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ABSTRACT

The guide begins with a discussion of the basis for science education by focusing on two questions: (1) Why teach science?, and (2) What is science? It considers science teaching and matching instruction to the learner, describes objectives for K-12 science curriculum, and analyzes decision making, providing recommendations and outlines. A process for developing a science curriculum is outlined, including worksheets for curriculum development, establishing parameters, identifying themes and learning activities, scheduling, and refining. The need for evaluation is stressed and test and item quality is reviewed. Current issues such as context of science teaching, K-6 time allocations, computers, careers, and equity in science education are considered. The curriculum is broken down by grade level: (1) K-2; (2) 3-6; (3) middle/junior high school; and (4) senior high school. At each level there is an overview, a discussion of curriculum development, a problem solving section, an elaboration of science knowledge for that level, an examination of the nature of science, a section on science, technology, and society, and a guide to evaluation. (JM)

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Wisconsin Department of Public Instruction
Herbert J. Grover, State Superintendent

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A Guide to Curriculum Planning
in
Science

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Foreword

In 1970, the Wisconsin Department of Public Instruction published a document titled *A Guide to Science Curriculum Development*. Although that effort produced a good definition of an effective science curriculum, it did not provide the detailed structure that local curriculum designers need to produce and implement a comprehensive science curriculum. The original publication provided a basis for the work of a group of state science educators, whose effort produced an informal document called the *Wisconsin Design for Science Education*. That design was used as the basis for several successful curriculum projects, notably in Wausau and Niagara.

With this background, the Science Curriculum Task Force was appointed in 1983 to build upon the work already done and produce a new guide—*A Guide to Curriculum Planning in Science*—that would provide the necessary guidelines for effective curriculum work at the local level. The task force has spent many hours developing the ideas that are presented here. The guide provides structure as well as a workable strategy for proceeding with a long-range plan that can result in an evolving K-12 science curriculum.

The recommendations in *A Guide to Curriculum Planning in Science* are based upon the best resources available. The guide is contemporary in learning theory as well as the theories of science and science education. I believe it will be a principal force in making dynamic and innovative science programs a reality in Wisconsin.

Herbert J. Grover
State Superintendent

Preface

A Guide to Curriculum Planning in Science is designed as a primary tool for local science curriculum committees and individual writers. Its structure for a science curriculum is based on a balanced treatment of four science education components. It has 22 detailed objectives and many examples of appropriate subobjectives and teaching activities to support each objective.

The guide also provides a rationale for the proposed structure and a discussion of the learning theory used as the basis for determining the emphasis on given objectives within ranges of grade levels. Evaluation recommendations are made throughout the document to emphasize the importance of both student and program evaluation as integral parts of ongoing curriculum development and modification. The guide presents a series of specific recommendations and five curriculum development options, to be chosen according to the time and resources that can be devoted to developing and maintaining the science curriculum.

Perhaps most important, the guide offers a detailed strategy for using the ideas presented to develop a system of science units or modules that can fit together to become an articulated K-12 science curriculum. There is a series of five worksheets and related directions for using them that can be used to get the curriculum writing process underway.

The guide does not have an extensive bibliography of resources nor attached appendices. The Science Curriculum Task Force concluded that these items would become obsolete before the structure offered in the guide will and, in that sense, tend to make the total guide less useful over time. The task force hopes to keep working to provide future supplementary documents, such as a resource guide, a guide to science curriculum implementation and maintenance, and a guide to evaluation.

Kenneth W. Dowling
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Acknowledgments

The Science Curriculum Task Force appointed by State Superintendent Herbert J. Grover was given the responsibility of developing ideas and writing the complete manuscript that has become *A Guide to Curriculum Planning in Science*. The task force met often and worked hard to complete the job to meet deadlines. The Department of Public Instruction gratefully acknowledges the task force members' commitment to producing a document that will be a valuable aid to local science curriculum planning and writing. The task force members are:

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Two key individuals at the Department of Public Instruction gave ongoing assistance to the process of developing the guide: Connie L. Haas, Program Assistant, and Jeanne R. Hook, Program Assistant. Essential to the writing process were the careful transcriptions of the guide's many revisions done by the DPI Word Processing Center. Susan A. Townsend and Debra Motiff, management information technicians, made the primary effort in transcribing the guide. The cover photo came from a collection at the Research and Development Center, University of Wisconsin–Madison. Other photos were provided by Neldine M. Nichols, Kathy Lee, Susan Tossi, and Ellen Baerman. Finally, special assistance with production came from Victoria L. Rettenmund, artwork and layout; Mary Holt Segall, editor; and Sarah Helfman, editorial assistant.

A Basis for Science Education

What is Science?
Why Teach Science?
Summary

What is Science?

Each person holds a unique perception of science. Yet, most people have difficulty precisely defining science. Many think of science as facts, principles, and natural laws that are revealed by nature. They believe scientists observe these revelations, learn them well, and apply them to their purposes. To these people, science often seems beyond their understanding, and scientists seem mysterious, special people, not always to be trusted. Philosophical thinkers see science as a creative process and scientists as those who start from careful observations to create explanations of natural events and interactions of living and nonliving forms. Teachers, because of limited experience in the practice of science, may limit their thinking about science to the explanations learned in lectures and from textbooks. Students often limit their definition to what their teachers tell them, the activities they do in laboratories or classrooms, and their science textbooks.

Overall, people's different perceptions of science can cause a communication barrier that makes developing a science curriculum difficult. The success of science education depends on breaking down that barrier by combining definitions to give curriculum developers a broad, realistic perception of science. Then science teachers are better equipped to help students become truly scientifically literate so that, as adults they will function well in a scientific and technological society, and perpetuate a better understanding of the nature and role of science in society.

Science education is best served when it is based on a comprehensive definition of science that views science as an activity involving power and politics, old and new knowledge, and safe and dangerous knowledge. Science education must accurately present science as an activity that has changed the way people think of the universe, and as an activity that sometimes alters the process and quality of life. The definition must be developed in a way that will be useful to the teacher in making curricular decisions which will ultimately benefit the student's understanding of science.

Four Components of Science Education

The working definition of science, for teaching purposes, should include four carefully integrated components.

Problem Solving. Science is, above all else, a problem-solving activity that responds to questions by collecting and analyzing data to offer explanations.

Science Knowledge. The knowledge that results from scientific problem-solving activity is organized into concepts, generalizations, and unifying principles, which lead to further interpretation of objects and events in the environment.

Nature of Science. Distinct patterns among physical activities and mental operations of scientists reveal the nature of science as a unique way of seeking knowledge.

Science, Technology, and Society. Science is practiced in a context of human culture, and, therefore, dynamic interactions occur between science, technology, and society.

Each component must be considered in detail before attempting to write a good working definition of science that can be used to develop a science curriculum.

Problem Solving

The process of science is always a problem-solving activity. It is a process that is informally practiced by everyone. For some it is natural and easy. For others it is difficult and limited in usefulness. It is a learned process that comes from experience. Problem solving in science seldom follows a linear sequence of actions or steps. False starts, surprises, and midstream decisions occur that cause starting over, replanning, and seeking alternate procedures. Yet, the general procedure is a sequence of four groups of actions: *questioning, collecting data, analyzing data,* and *explaining results.* Within each of these action groups are several specific actions, each requiring its own special skills and understandings. These specific actions are learned through practice and repetition. They can be applied in very simple situations or in complex, extended studies.

Problem solving in science seldom follows a linear sequence of actions or steps.

It is important in considering science education to distinguish between these actions as they may be applied by anyone seeking to solve problems in science and the actions of scientists involved in empirical investigations. Although the two processes have much in common, they differ in degree and formality. The process of problem solving practiced by students is detailed in table 1. This table is used in later sections of this guide to show the specific actions to be emphasized at the grade levels.

Table 1

Problem-Solving Action Groups

Questioning ↔	Collecting Data ↔	Analyzing Data ↔	Explaining
Noting patterns	Observing	Predicting	Describing
Noting discrepant events	Measuring and quantifying	Inferring	Defining
Seeking information	Identifying significance	Graphing	Interpreting
Formulating questions	Selecting variables	Tabulating	Developing mental models
Generating hypotheses	Estimating	Using numbers	Developing physical models
		Correlating	Communicating
		Classifying	

Performance-based skills are associated with each specific action.

The curriculum must be designed to develop student competence in specific problem-solving skills in addition to the ability to apply those skills to real problems. The processes shown in table 1 may be used as the structure for teaching problem solving as one of the four components of science education.

Science Knowledge

Science knowledge accumulates slowly as scientists work to construct explanations of observable phenomena. This knowledge aids in understanding how the universe operates and helps people to evaluate their place, significance, and role in the total environment. Over the years, science knowledge has been divided into areas of investigation or disciplines, such as biological, physical, and earth sciences. While disciplinary divisions have been valuable to practicing scientists, they have frequently restricted the learning process because many concepts and problems involve two, three, or more science disciplines as well as other subject areas. For this reason, in elementary and secondary education, concepts that apply to more than one discipline should be used to understand the interrelationships among the science disciplines. This kind of learning is encouraged when the science knowledge component of the curriculum is organized around major conceptual schemes. The conceptual schemes then become organizers for specific discipline concepts which, in turn, are derived from concepts specific to phenomena. Six conceptual schemes that provide a useful and versatile framework for teaching science knowledge are presented in table 2.

Conceptual schemes become organizers for specific discipline concepts which, in turn, are derived from concepts specific to phenomena.

■ Table 2

Science Knowledge

Diversity. Natural phenomena display a wide variety of similarities and differences.

Change. The natural environment is constantly undergoing change.

Continuity. There is constancy in cause-and-effect relationships which makes change explainable.

Interaction. The interactions of matter and energy determine the nature of the environment.

Organization. Related systems within systems comprise the universe.

Limitation. Natural phenomena are limited by the fundamental nature of matter and energy.

The six conceptual schemes, when first encountered, seem quite simple. Certainly, they include the early concepts of traditional elementary programs—similarities and differences in living things, changes in seasons, growth, properties of objects. But they also include the most complex concepts—biological taxonomy, energy exchange, force fields, entropy. The schemata are chosen to be as comprehensive as possible. They are the organizing concepts for science knowledge in the entire science curriculum. They should be presented in a rich variety of contexts and at various levels of sophistication. Each scheme should be presented as it applies to the general fields of the biological, physical, and earth sciences. The strategies for making such applications at specific grade levels are described in later sections of this guide.

Nature of Science

Science is an activity of people, called scientists, who are subject to all of the limitations, biases, and errors of trained and experienced people working in other human enterprises. Yet, science is conducted in accordance with informal rules and assumptions that regulate what scientists do. These rules and assumptions comprise a philosophy of science that has developed over centuries from the experiences of those who have struggled to understand natural objects and events.

Knowing this philosophy of science is critical to an understanding of science as a workable and effective process in which scientists act in response to phenomena and shared interests. Knowing about the actions and interactions of scientists helps students understand the strengths as well as the limitations of the scientific process and the ways in which it can be best applied.

Understanding the nature of science requires knowing that science is a creative human endeavor similar to the pursuit of art, music, or literature. A new theory in science is as much a creation as a musical composition or theatrical production. All help us understand ourselves and our world. Scientific theory, like the products of other creative endeavors, is subject to extensive study by other members of the profession who will critique, and sometimes change, the creation. There is a unique characteristic in both the nature of a new scientific development and the actions and interactions through which it is produced. Unlike other creative activities, the products of science must relate directly to the real world, and, therefore, may be subjected to repetitive tests. For this reason, science knowledge is certified knowledge. That is, science knowledge has been tested, has withstood critical review, and is consistent with what is observed in the real world.

. . . the products of science must relate directly to the real world and, therefore, may be subjected to repetitive tests.

There are three elements that provide guidelines for teaching and learning the nature of science: the history of science, the philosophy of science, and the actions and interactions of scientists. These elements are expanded in table 3.

Table 3

Nature of Science

- *History of Science*

  Evolution of Science. The knowledge and processes of science have evolved over a long period of time.

  Milestones. Science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

- *Philosophy of Science*

  Assumptions. Science is based upon assumptions about nature.

  Accepted Rules. Scientists operate within a generally accepted set of rules.

- *Actions and Interactions of Scientists*

  Variety of Methods. Scientists use a variety of methods to solve problems.

  Science/Technology. Science and technology are interdependent activities.

  Creative Enterprise. Science is a creative enterprise.

Understanding the nature of science is the basis for personal evaluation of information that may be presented as being scientific. It is essential that the scientifically literate person be able to detect the difference between science and pseudoscience, between fact and belief. Knowing what science has been makes it possible for individuals to understand the role of science in the present and its probable role in the future.

The science curriculum should be organized to engage students in activities that will emphasize the nature of science as one of the four components of science education. These activities often should include case studies and analyses of the behaviors and motives of known scientists at different periods in history. Examples of activities, given later, will demonstrate ways this can be done.

Science, Technology, and Society

Although science is often described as having no purpose other than the pursuit of knowledge, it is usually true that new knowledge is useful and can be applied to the production of goods and services to be used in some way by segments of the world society. The term technology, when used in science education, refers to investigating ways that knowledge can be applied. When used in this sense, the process of technology is often similar to the process of science. The two interact closely. Scientists often use knowledge to produce special equipment. Technologists often seek new knowledge. The two processes, in practice, are hard to separate. Put another way, the pursuit of knowledge and the application of knowledge are often conducted together with an intent to affect society.

Over time, the developing science knowledge and the ways it has been applied have caused the value structure of society to change. For example, when Copernicus proposed a sun-centered model of the solar system (through questioning, collecting data, analyzing data, and explaining results) accepted beliefs were shaken and a new perception of the place, significance, and role of the human race evolved. A fundamental value had changed. More recently, when science and technology made it possible to view earth from space, people for the first time began to realize how finite it is. As a result, arguments to protect the earth and prevent environmental degradation had a new meaning.

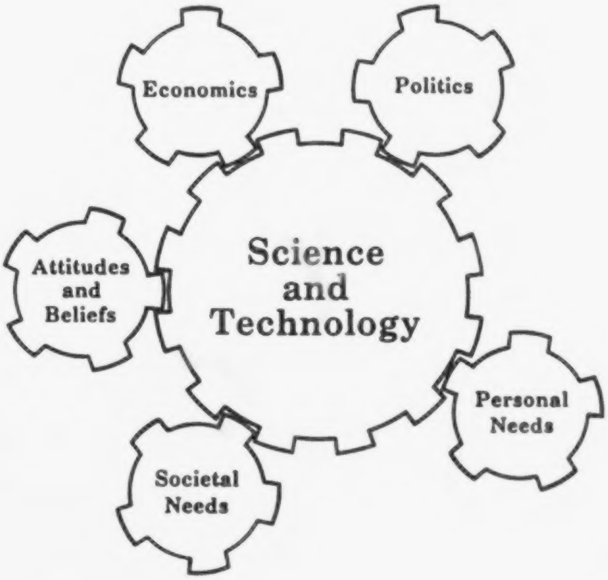
Science and technology affect personal values and those values taken together become the value structure held by society. But science and technology do not act independently of society. As values change, the motivation and support for efforts that may lead to new discoveries, or opposition to them, change. Society pays the bill and gets the benefits as well as the problems that result from the discoveries.

Science and technology affect personal values and those values taken together become the value structure held by society.

There are five aspects of society that interact with science and technology. They are: political strength, economic power and security, common attitudes and beliefs, societal needs, and personal needs. These aspects are displayed graphically in figure 1 to show that each interaction has the effect of driving the whole system while science and technology play a central role in all five interactions.

Figure 1

Interaction of Science, Technology, and Society



Because the achievements of science and technology influence society, and because society either supports or limits the progress of science and technology, the science curriculum should be structured to develop awareness of the interactions of science, technology, and society, the fourth component of science education. The interaction of science, technology, and society can be described specifically, as shown in table 4.

■ Table 4

Science, Technology, and Society

Attitudes and Beliefs. Progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

Economics. Science and technology influence economic growth which, in turn, affects the progress of science and technology.

Politics. Science and technology influence political processes which, in turn, affect the progress of science and technology.

Societal Needs. Developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Personal Needs. Science and technology can affect individual lifestyles and the individual, in turn, responds to affect science and technology.

A Working Definition of Science

Based on the four components of science education, a working definition of science can be derived that is useful for structuring the science curriculum.

> **Science is a human activity through which problems and questions dealing with natural phenomena can be identified and defined, and solutions proposed and tested. In this process, data are collected and analyzed, and available knowledge is applied to explaining the results. Through this activity, investigators add to the store of knowledge, thereby helping people better understand their surroundings. Applications of this knowledge also may bring about changes in society and the cultural order and may have a direct bearing on the quality of life.**

This working definition should not be memorized by teachers or students. Rather, it should provide a guideline for curriculum planning, implementation, and evaluation that will more effectively bring science into the teaching/learning process.

Why Teach Science?

The rationale for including science as a critical component of the school curriculum in all grades is linked to the foregoing working definition of science. At a personal level, competence in science gives individuals confidence to respond intelligently to objects and events of nature, and to control some aspects of their personal environment and destiny. At a societal level, overall competence, or literacy, in science for all citizens is necessary to assure stewardship of our planet and the human condition. Effective education in science, at both personal and societal levels, is a necessary goal of education in the United States. Because science and technology so strongly interact with society and affect everyone's life, it is necessary for students to understand science as a dynamic social phenomenon. Science education must help students to understand and, indeed, shape the ways in which science will affect the future quality of life. Why teach science? The major reason is to develop scientifically literate persons who together become a scientifically literate society.

At a societal level, overall competence, or literacy, in science for all citizens is necessary to assure stewardship of our planet and the human condition.

There are recognized attributes that describe a scientifically and technologically literate person. Each attribute should be thought of as describing part of a continuum along which the individual may progress. The progress of the individual's science education should be equated with progress along this continuum. The scientifically and technologically literate person

- uses science knowledge, problem-solving skills, and informed attitudes in making responsible everyday decisions;
- understands how society influences science and technology as well as how science and technology influence society;
- understands that society limits science and technology through the allocation of resources;
- recognizes the potential as well as the limitations of science and technology in advancing human welfare;
- has a broad understanding of the conceptual schemes of science knowledge and is able to apply them;
- has an intellectual interest in science and technology;
- understands that new science knowledge results from an inquiry process that uses existing knowledge;
- distinguishes between science knowledge and personal opinion or belief;
- recognizes the origin of science, and understands that scientific knowledge is tentative and subject to change;
- understands the values of technology as well as the problems that can result from its uncontrolled use;

- uses knowledge and experience to evaluate the worthiness of research and technological development;
- has a richer and more exciting view of the world as the result of science education.

The same "hands on" science activities that promote intellectual development during early school years may simultaneously serve the development of reading, mathematical, and social skills.

Clearly, scientific literacy cannot be pursued in isolation from other branches of thought and academic pursuit. Indeed, the strong relationships of science to language arts, mathematics, social studies, and other areas indicates the value of integrated treatment of science with other curricular areas. The same "hands on" science activities that promote intellectual development during early school years may simultaneously serve the development of reading, mathematical, and social skills. Therefore, another answer to "Why teach science?" resides in the potential of science education to complement other curricular areas. This complementarity can exist through all school years. If carefully planned, integration of science with other subjects will promote more efficient use of time in school.

In a world community which is increasingly competitive in producing scientific and technological goods and services, it is increasingly important to address ways in which science education may affect, directly and indirectly, both national concerns and individual career and leisure activities. Scientific literacy is needed for both the future scientists who will directly contribute to science nationally and internationally, and the citizens who will indirectly shape the future course of science. A strong, sustained effort in science education is necessary to assure individual, national, and international welfare.

Summary

The curriculum should be directed toward internalizing the working definition of science.

The most effective science curriculum will be one where students experience a continuum of activities with appropriate emphasis on the four components of science education. The curriculum should be directed toward internalizing the working definition of science. This, of course, requires that provision be made for specific learning activities that involve all four components. Often science curricula over-emphasize the knowledge component at the expense of the other components—problem solving, the nature of science, and the interaction of science, technology, and society. This common tendency results from a similar over-emphasis of the knowledge component in science textbooks and in the content of science courses organized by specific science disciplines. The intent of *A Guide to Curriculum Planning in Science* is to encourage the development of science curricula that balance the four components of science education. The subsequent sections of this guide will relate to the working definition of science (see p. 8) as each of the components of science education is addressed for curriculum development purposes.

Science Teaching and Student Characteristics

2

Focus on the Learner
Matching Instruction to the Learner

Focus on the Learner

When making curriculum decisions all aspects of teaching and learning need to be considered. Curriculum developers often concentrate on the content to be taught without giving full consideration to how students learn and develop concepts. Consequently, course content frequently is not compatible with the intellectual development of the students. Often students are expected to deal with concepts they neither understand nor comprehend. A curriculum's success is not due to the logical sequence of its content, but, rather, to the ability of students to learn, understand, and use the content.

A curriculum's success is due to the ability of students to learn, understand, and use the content.

The teaching methods used in science instruction do not differ greatly from those used in teaching other subjects. However, present-day science courses are taught in an atmosphere of inquiry. Such an atmosphere provides opportunities for students to explore the natural world and experience its phenomena, while developing an understanding of science generalizations. During this process, students will gain problem-solving skills. Laboratory and field activities have become an important teaching method in science education and an integral part of science curricula. When the laboratory is used extensively, the activities must be designed to be compatible with the intellectual development of students.

Matching Instruction to the Learner

Curriculum designers must make a conscious effort to carry out the following tasks when planning and implementing a new science curriculum.

- Determine the knowledge content of the curriculum. Take care to match the content to the students' past experiences and their level of intellectual development.
- Identify the level of problem-solving skills of each child in the classroom.
  - Select the methods most appropriate for teaching students at the identified level of problem-solving skills.
  - Provide learning experiences that will help the students move from their present level of problem-solving skills to the next higher level.

Current learning theories can provide science teachers with insights into how students learn and how instruction affects cognitive development. Such insights help teachers make decisions about the knowledge content of curricula and appropriate teaching techniques. Learning theories that have proven helpful are those developed by Robert Gagne, David Ausubel, Jean Piaget, and Joseph Novak.

Determining Knowledge Content of the Curriculum

One of the first curriculum decisions a teacher must make is to determine the content to be taught to the learner, knowing that the content is limited by the student's ability to learn it. Teachers cannot expect students to learn material that is too difficult for them to understand, nor can teachers expect students to be interested in re-learning material that is already a part of their intellectual framework. One of the important tasks of the teacher is to match curriculum content to the learner's past experiences and intellectual development. David Ausubel has stated that the most important single factor influencing learning is what the learner already knows. Each individual has a unique history of learning experiences and brings to any learning situation a unique existing knowledge base. By determining the learner's knowledge base, the teacher knows the starting point for new instruction.

One of the important tasks of the teacher is to match curriculum content to the learner's past experiences and intellectual development.

New knowledge is incorporated into the existing concepts of the learner. Meaningful learning occurs only when the learner's existing concepts are modified by new knowledge. If the learner *does not* possess basic concepts into which the new knowledge can be incorporated, *no* meaningful learning will occur. It is essential that the missing concepts be taught so that the planned learning will be meaningful.

The concepts developed by a young learner progress from very general ones to more complex ones. A young child will possess concepts such as hot, cold, color, dog, and cat. By school age, most will have developed between 1,000 and 2,000 concepts. As a child learns, new information is added to the existing information within the brain, and linkages develop between the old and new elements. As the concepts become interlinked, broader and more inclusive concepts are developed. A child's concept of a dog may broaden to include different species of dogs and then animals similar to dogs, such as wolves and foxes. New knowledge continually modifies the existing concepts throughout the learner's life. As more learning occurs, more concepts are modified and the cognitive structures of the learners become more and more inclusive. With more highly organized conceptual structures, the learner becomes more able to think abstractly and formulate solutions to problems.

Identifying Individual Problem-Solving Skills

In order to provide meaningful learning experiences for students, it is necessary to know, with high probability, what learners already know and what cognitive structures they possess. Once this is known, teachers can begin planning learning experiences and sequencing the knowledge to be learned.

Jean Piaget developed his learning theory after studying how children solved problems he presented to them. He observed that all children progress through the same stages of problem solving, beginning with simple skills at early ages, and developing more complicated skills as they matured. Science teachers have found that understanding the stages of problem solving as described by Piaget has helped them plan curricula and classroom activities for teaching science. The problem-solving stages are summarized in table 5.

Although the levels are only approximate, they are the basis for grade-level groupings in this guide.

Children do not progress abruptly from a less complex to a more complex problem-solving stage. Therefore, it is common for a child to use more than one thought pattern at the same time, depending on the problem being solved. The age ranges given in the chart are not absolute. Intellectual development, just as physical growth or the development of a social consciousness, is not identical in all children. Among the factors influencing the development of problem-solving ability in children, four factors appear to be most influential.

- Level of physical and mental maturation (nutrition level, amount of brain growth)
- Past and present physical experiences (where they have been, what they have seen, what they have handled, manipulated, and experienced)
- Number of opportunities available for sharing experiences with others (adults, teachers, other children)
- Degree to which new learning has caused a reorganization of the conceptual framework.

Selecting Appropriate Methods

Information about the stages of problem-solving skills commonly found in children, the environmental and experiential factors that influence the development of more complex problem-solving skills, and the manner in which learners develop and expand their conceptual knowledge can be incorporated into a method for teaching science.

Neither books nor new technology can take the place of direct experience in the laboratory.

Regardless of the complexity of their problem-solving skills, students can learn about their world by manipulating and interacting with its elements. For this reason, it is essential that any program of science instruction be based upon laboratory activities. Neither books nor new technology can take the place of direct experience in the laboratory. It can be demonstrated that lack of hands-on experience or direct interaction with physical objects in the environment results in students performing below their potential. The laboratory as a learning place is unique to science instruction. It provides a place where students can explore phenomena and develop their problem-solving skills. Experience in the laboratory helps students to move from one problem-solving level to the next.

Problem-Solving Stages

Name of Problem-Solving Stage	Approx. Age of Occurrence	Approx. Grade Level	Common Problem-Solving Skills
Preoperational	2 – 7	K–2	Thinks only about what is being acted upon Thinking is irreversible Behavior is egocentric Centers attention on only one detail of an event Reasoning is not based on accepted adult logic
Concrete Operational	7 – 12	3 – 6	Understands the conservation of number and amount of matter Can classify if given a classification system Produces new knowledge by reorganizing existing concepts Operates logically on real objects but not on ideas
Transitional	11 – 15	Middle/Jr. High School	Can apply memorized formulas, words, or phrases Can understand someone else's mental model, but has trouble developing own Mixes the thought patterns of formal thinking and concrete thinking Can use formal reasoning, but not when rushed or hurried
Formal Operational	14 – 18	Senior High School	Begins solution of a problem by suggesting probable hypotheses Thinks in the future Can manipulate more than one variable at the same time Thinks abstractly Forms theories as explanations

Another factor influencing the development of problem-solving skills is the opportunity learners have to share experiences with each other. Therefore, when organizing laboratory groups, teachers should include individuals with varying degrees of concrete, transitional, or formal problem-solving skills in the same group. This will allow them to interact with each other to learn how each approaches and solves problems. In addition, teachers should plan class activities that allow students to share their experimental results and explanations. Following direct laboratory experience, science concepts should be formalized through discussion, labeling, reading, or application to a new situation. These activities will help the students to interrelate new concepts with previously learned ones.

Helping Students Progress

Science instruction should incorporate exploratory problem-solving laboratory activities, opportunities for discussing and sharing student laboratory experiences, and the formal presentation of new concepts to expand conceptual development and sharpen problem-solving skills of the learner. Each of these elements contributes to the intellectual development of the learner and should be considered an integral part of any science education program.

Conceptual development is influenced by past experience and the manner in which new experiences are fitted into an existing conceptual framework.

As children pass through different levels of development their learning environment can influence their progress to the next highest level of problem-solving skills. Conceptual development is influenced by past experience and the manner in which new experiences are fitted into an existing conceptual framework. If a program of science education is to be based on this learning theory, teachers are faced with the following tasks.

- Identifying the level of problem-solving skills possessed by the students in the classroom
- Selecting the teaching methods most suitable for students possessing the level of problem-solving skills identified
- Organizing the classroom learning environment so that the students will be able to develop the problem-solving skills of the next higher level of intellectual development

If these three tasks are considered when designing a K-12 science program, the program will be geared to the students' intellectual capabilities, and will permit them to learn new knowledge and incorporate it meaningfully into their existing conceptual framework. A summary of the limitations of students and a description of appropriate problem-solving activities for four grade level groupings are given in table 6.

Table 6

Developmental Problem-Solving Skills Across Grade Levels

When learning experiences incorporating the thinking processes of the next higher level are provided, students tend to progress from one level of problem-solving skills to the next.

Grades K-2

Basic activities should involve students in

- making observations of the objects around them (How many? What colors? What structure?)
- comparing physical properties (How are things alike? How are things different?)
- making direct measurements (How long? How tall? How heavy?)
- talking about their observations

. . . AND ALSO . . .

provide exposure to basic 3-6 activities

- classifying and ordering items using one variable (largest to smallest, shades of color)
- using observations to draw simple conclusions
- predicting possible results based on past experiences
- describing the thought processes used to reach a conclusion
- using trial and error to solve problems
- comparing the past with the present

BE AWARE students of this age have difficulty

- *accepting a point of view other than their own*
- *thinking in the past tense*
- *thinking in the future tense*
- *comparing objects by two or more characteristics at the same time (color and length, width and length, texture and color)*
- *understanding a logical sequence of thought (A leads to B, B leads to C, then A leads to C)*
- *learning about objects and their properties only by reading about them and not physically experiencing them*
- *dealing with abstract ideas and thought patterns (energy, tomorrow, evolution, atoms)*

Grades 3-6

Basic activities should involve students in

- using their observations to draw simple conclusions
- classifying and ordering items using one variable (largest to smallest, shades of color)
- using trial and error to solve problems
- predicting possible results based on past experiences
- describing the thought processes used to arrive at conclusions
- comparing the past with the present

. . . AND ALSO . . .

provide exposure to basic 3-6 activities

- predicting unknown data from data that are known (extrapolate)
- understanding a thought sequence based on simple logic (A leads to B, B leads to C, then A leads to C)
- dealing with simple abstract ideas
- visualizing simple models presented to them
- discovering cause-and-effect relationships
- intuitively understanding proportions

BE AWARE students of this age have difficulty

- *thinking abstractly*
- *formulating many alternative solutions to a problem*
- *making a formal hypothesis that includes a possible cause and predicts a possible outcome (if . . . then reasoning)*
- *approaching a problem through formal sequential reasoning (do A, then B, then C)*

Middle/Junior High

Basic activities should involve students in

- predicting unknown data from data that are known (extrapolate)
- understanding a thought sequence based on simple logic (A leads to B, B leads to C, then A leads to C)
- dealing with simple abstract ideas
- visualizing simple models prepared by someone else
- discovering cause-and-effect relationships
- intuitively dealing with proportions

. . . AND ALSO . . .

provide exposure to basic senior high school activities

- attacking problems systematically
- using a logical thought process as part of their normal thinking pattern
- making a formal hypothesis which includes a possible cause and predicts a possible outcome
- designing controlled experiments
- foreseeing all combinations of variables in an experiment
- including mathematical relationships in conclusions and expressing proportional relationships

BE AWARE that students of this age have difficulty

- *making a formal hypothesis which includes a possible cause and predicts a possible outcome (if . . . then reasoning)*
- *devising their own controlled experiment*
- *predicting possible sources of error in an experimental design*
- *building their own models*
- *solving problems using proportional relationships*

Senior High School

Basic activities should involve students in

- using logical thought processes as part of their normal thinking
- making a formal hypothesis that includes a possible cause and predicts a possible outcome (if . . . then reasoning)
- designing a controlled experiment
- determining all combinations of variables in an experiment
- including mathematical relationships in conclusions
- expressing proportional relationships

. . . AND ALSO . . .

provide opportunities to students for

- practicing and refining their abstract problem-solving skills
- using concrete problem-solving skills if necessary

BE AWARE that although it is implied that formal abstract thought processes are present in the high school grades, not all high school students have attained this level of problem-solving skills.

These grade-level groupings have been used to develop the four components of science education in sections 8-11.

Objectives for a K–12 Science Curriculum

3

Goals for Science Curriculum Components
K–12 Science Education Objectives

Goals for Science Curriculum Components

Problem solving; science knowledge; nature of science; and science, technology, and society: these four components of science education are the cornerstones of the K-12 science curriculum. The terms are identifiers for the broad range of concepts and skills they represent. To progress to the next stage in science curriculum development, it is necessary to identify the major objectives that comprise each component. These objectives can, in turn, be broken down into subobjectives, which may themselves be broken down further. This process finally leads to the fine structure of the curriculum, which defines the grade-by-grade and day-by-day details of classroom activity.

Each of the four components of science education can be considered to have one major goal.

. . . competence

- The goal of the *problem solving component* is *competence*. All of the specific actions or processes that are a part of problem solving require an ability to perform an operation. As these skills accumulate, competence emerges to solve problems.

. . . knowledge

- The goal of the *science knowledge component* is *knowledge*. It is difficult to do anything in science without knowing the results of scientists' work in the past. A context of science knowledge is present in every investigation and is necessary to understanding the nature of science and its impact.

. . . appreciation

- The goal of the *nature of science component* is *appreciation*. Science and technology have developed as human enterprises that have brought understanding as well as satisfaction and comfort to humankind. The power of science is derived from an invention of the human mind that needs to be understood to be appreciated.

. . . wisdom

- The goal of the *science, technology, and society component* is *wisdom*. The power of science and technology can serve society well only if decisions controlling that power are made with wisdom, which comes from prudent use of knowledge. Everyone in society has the responsibility to participate in these decisions.

In the process of establishing this guide's objectives for K-12 science education, the Science Curriculum Task Force agreed that an important outcome for students is having positive science values. Students should value the problem-solving process, the knowledge science has produced, the nature of science, and the interaction of science and technology with society. These values have a basic cognitive component. Positive values are attained through meaningful teaching and learning of concepts and skills. If the teaching of cognitive content and investigative skills is not meaningful to students, they will develop negative feelings about science and their personal relationship to it.

The 22 objectives that comprise the four components do not include explicit statements of values as necessary student outcomes. However, it is implicit that desirable values are related to the objectives. Any time concepts and skills are taught, values are associated with them.

Science Education Objectives

The objectives listed in table 7 are to be achieved through a continuous K-12 curriculum. This requires that each objective be studied to identify the subobjectives appropriate for each grade level. In the grade-level sections of this guide, examples of subobjectives are given—but these are only examples. The lists are not intended to be complete. Applying the objectives to the curriculum development process is demonstrated in the examples of activities in the guide's grade-level sections. When selecting objectives or subobjectives, consideration needs to be given to the students' problem-solving skills, the balance among the four science education components, and the recommended emphasis of the objectives at given grade levels.

In table 7, each objective is given a coded number and a one- or two-word identifying term. The numbers and identifiers will be used in various places in the remaining sections of the guide to represent the complete statements given here. Curriculum developers can refer back to this list as needed for full statements of the objectives.

Figure 2, which follows the science education objectives on p. 24, helps to visualize the totality of science education and suggests that the science curriculum should be organized to treat the four science education components at all grade levels.

The overall structure of the K-12 science curriculum comes from the interaction of the 22 objectives in the four science curriculum components with the nature of the learner. This interaction is shown graphically in figure 2. Note that all of the objectives can be treated to some extent at every grade level. As time allocated to teaching science is increased, the effort given to the objectives, as well as the sophistication of treatment, is increased.

In actuality, the nature of children and the way they learn makes it necessary to emphasize some of the objectives earlier than others. Although figure 2 implies equal emphasis at all levels, it is necessary in early grades to select the objectives that can be adapted to the concrete, experiential thinking of children. As their ability to reason and solve problems increases, the objectives that require more abstract treatment can be emphasized. This changing emphasis is indicated in table 9, p. 28, and in the introduction to each grade-level section.

Table 7

K-12 Science Education Objectives

1.0 Problem Solving

1.1 **Ask Questions.** The student shall ask answerable questions about nature.

1.2 **Collect Data.** The student shall collect pertinent data from nature.

1.3 **Analyze Data.** The student shall analyze data.

1.4 **Explain.** The student shall use the results of analysis to explain natural phenomena.

2.0 Science Knowledge

2.1 **Diversity.** The student shall understand that natural phenomena display a wide variety of similarities and differences.

2.2 **Change.** The student shall understand that our natural environment is constantly undergoing change.

2.3 **Continuity.** The student shall understand that there is constancy in cause-and-effect relationships which makes change explainable.

2.4 **Interaction.** The student shall understand that the interactions of matter and energy determine the nature of the environment.

2.5 **Organization.** The student shall understand that related systems within systems comprise the universe.

2.6 **Limitation.** The student shall understand that natural phenomena are limited by the fundamental nature of matter and energy.

3.0 Nature of Science

3.1 **Evolution of Science.** The student shall understand that the knowledge and processes of science have evolved over a long period of time.

3.2 **Milestones.** The student shall understand that science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

3.3 **Assumptions.** The student shall understand that science is based upon assumptions about nature.

3.4 **Accepted Rules.** The student shall understand that scientists operate within a generally accepted set of rules.

3.5 **Variety of Methods.** The student shall understand that scientists use a variety of methods to solve problems.

3.6 **Science/Technology.** The student shall understand that science and technology are interdependent activities.

3.7 **Creative Enterprise.** The student shall understand that science is a creative enterprise.

4.0 Science, Technology, and Society

4.1 **Attitudes and Beliefs.** The student shall understand that progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

4.2 **Economics.** The student shall understand that science and technology influence economic growth which, in turn, affects the progress of science and technology.

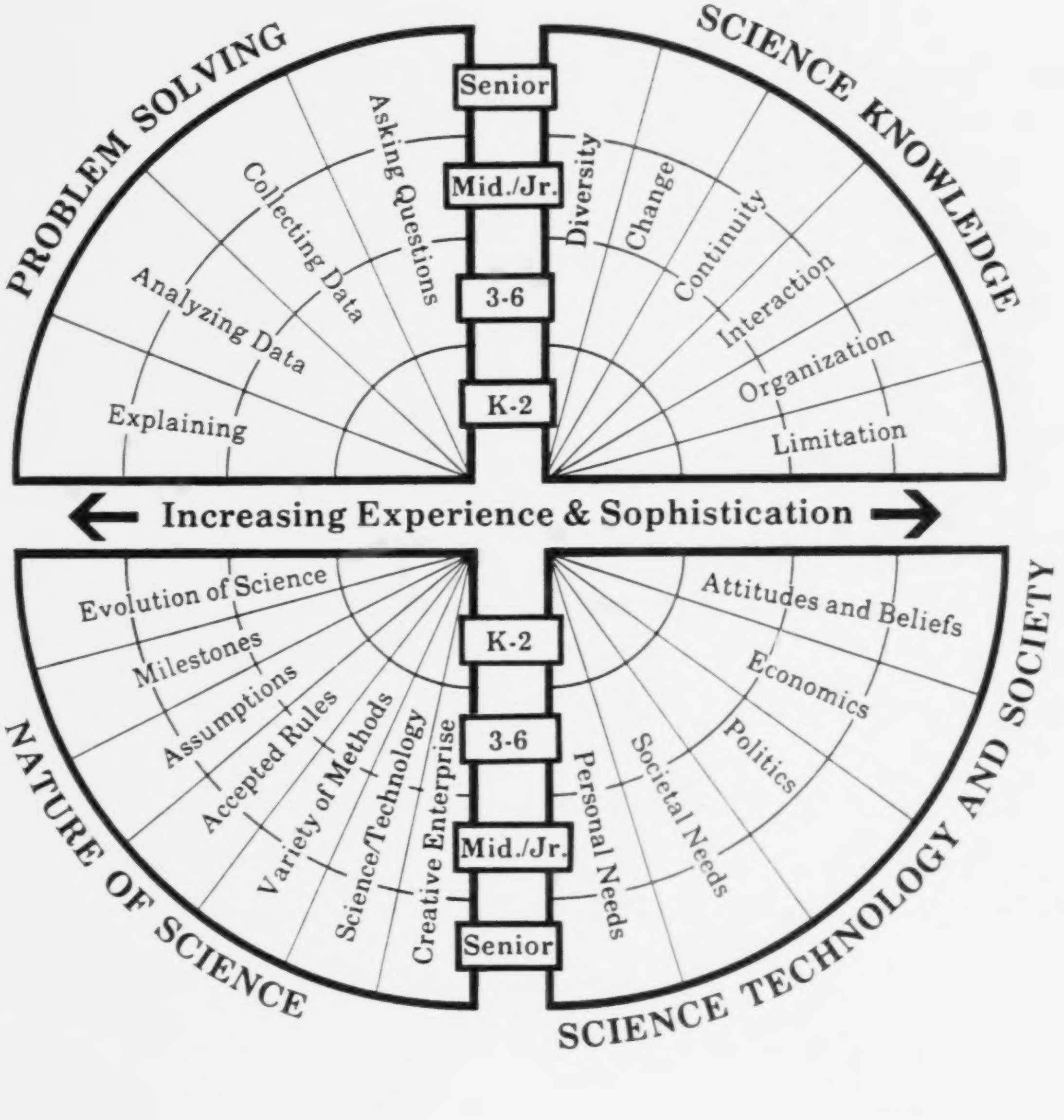
4.3 **Politics.** The student shall understand that science and technology influence political processes which, in turn, affect the progress of science and technology.

4.4 **Societal Needs.** The student shall understand that developments in science and technology affect the condition of life, and, in turn, society's response to scientific developments affects the direction of research and development.

4.5 **Personal Needs.** The student shall understand that science and technology can affect individual lifestyles and that the individual, in turn, responds to affect science and technology.

Figure 2

Four Science Curriculum Components


PROBLEM SOLVING
SCIENCE KNOWLEDGE
Senior
Mid./Jr.
3-6
K-2
Asking Questions
Collecting Data
Analyzing Data
Explaining
Diversity
Change
Continuity
Interaction
Organization
Limitation
Increasing Experience & Sophistication
Evolution of Science
Milestones
Assumptions
Accepted Rules
Variety of Methods
Science/Technology
Creative Enterprise
K-2
3-6
Mid./Jr.
Senior
Personal Needs
Societal Needs
Politics
Economics
Attitudes and Beliefs
NATURE OF SCIENCE
SCIENCE TECHNOLOGY AND SOCIETY

Making Initial Decisions

Recommendations
Options

Recommendations

All eight recommendations are important to achieving the objectives.

A very effective and efficient program is needed to achieve the 22 objectives in the four components that comprise science education. This involves more than a written curriculum. It involves a carefully developed strategy for implementation and maintenance of the curriculum. The following eight recommendations are important to that strategy. *Certainly, each set of circumstances dictates the procedures that can be followed, but as far as possible these recommendations should be followed.*

Teach Science at All Grade Levels

Students should learn through their educational experience that science is one process used to know about the world in which we live. Students can gain this concept by having continual educational encounters with the problem-solving skills of science and the knowledge generated by these procedures. They should graduate from high school as scientifically literate individuals who understand that the scientific enterprise influences their lives as it interacts with society. A scientifically literate citizenry is produced only when the schools make a concerted effort to include science instruction at all grades.

Provide a Balanced Treatment of the Four Science Curriculum Components

The four components of a science curriculum are: problem solving; science knowledge; the nature of science; and, science, technology, and society. Often science curricula have been based on the science knowledge component and the other three have been neglected. If the major goal of science instruction is the production of scientifically literate individuals, this over-emphasis on teaching knowledge has to be changed so that all four components are addressed.

In a K-12 science curriculum, the emphasis on the individual components is different at the various grade levels. For example, problem solving receives more emphasis in grades K-2 than in the senior high school, while knowledge receives more emphasis at the higher levels and lower emphasis in K-2.

Allocate Adequate Time for Teaching Science at All Grade Levels

The Wisconsin Department of Public Instruction has made recommendations for minimum instructional time allocations for eight of the major subject areas for grades K-6. The time allocations for the eight subjects are shown in section 7. The recommended minimum time to be allocated to science instruction, taken from the overall recommendations, is shown in table 8.

■ Table 8

Time Allocation for Science Instruction

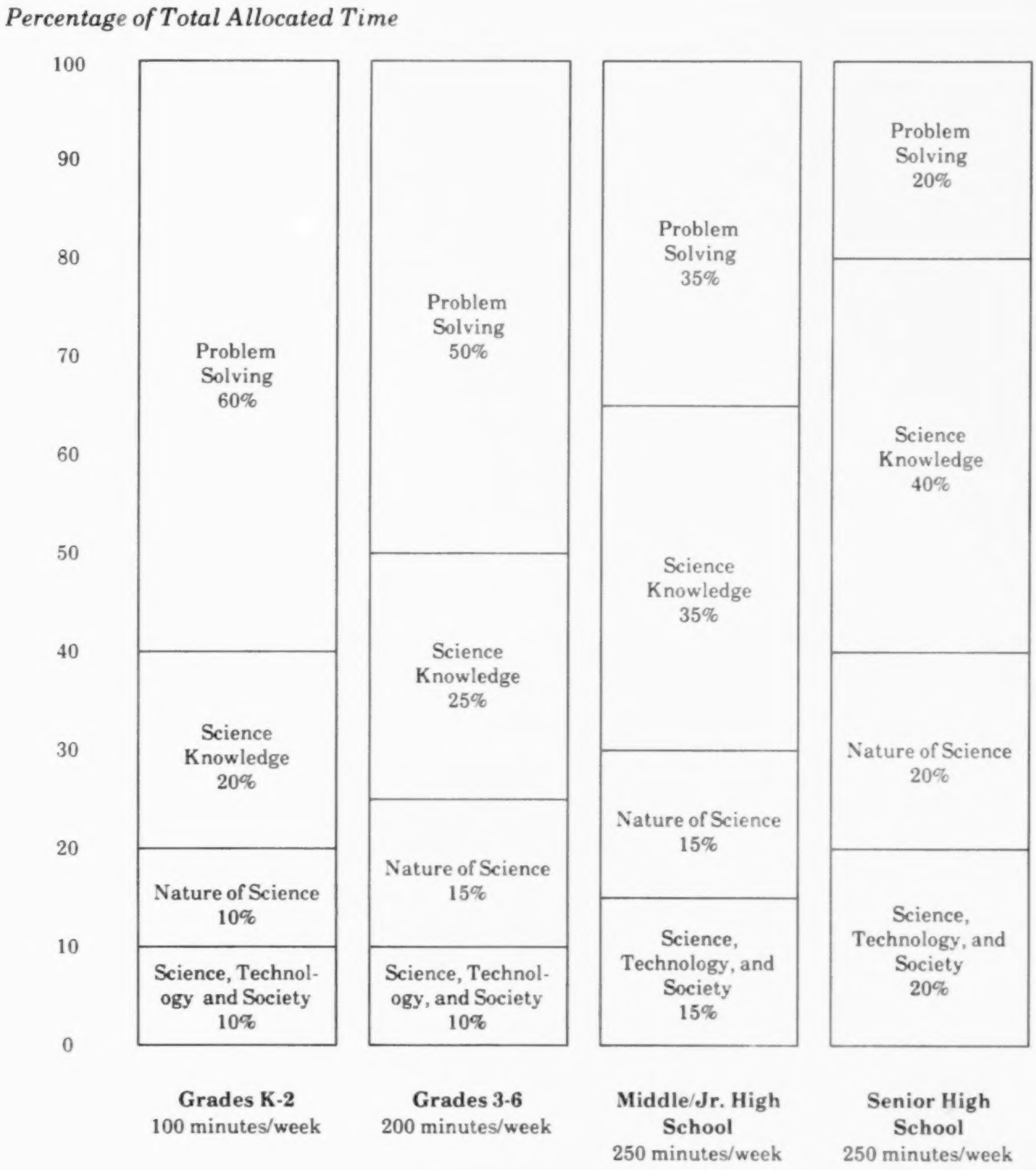
Grade	K	1	2	3	4	5	6
Time	10% of total time	100 min/wk	100 min/wk	150 min/wk	150 min/wk	175 min/wk	250 min/wk

Beyond sixth grade, DPI recommends that all required science courses meet for one full class period every school day. All students should be required to take science throughout junior high school. All students, by state law, must earn two credits in science in grades 9-12. State law also requires a written, sequential science curriculum plan; regular instruction in science in all elementary grades through grade 8; and that the program enables students in grades 9-12 to study science each year.

Table 9 indicates the average instructional time and relative emphasis on the four science curriculum components at four levels in the K-12 science curriculum. Note that the amount of time devoted to science instruction increases from 100 minutes at the K-2 level to 250 minutes at both the 7-9 and 10-12 levels. Also, the relative emphasis of each of the four components changes; this relative emphasis is treated in greater detail in sections 8-11. Meeting or exceeding the recommended minimum time allocations when designing a K-12 science curriculum will result in science being taught in all grades, with all four components of the curriculum model receiving appropriate emphasis.

Table 9

Science Components Emphasis/K-12



Articulate a K-12 Science Curriculum

A K-12 science curriculum must be planned so that the objectives are a part of the science experience of all graduates of the school system. In a well articulated science curriculum, currently learned knowledge and skills will be linked to past learnings. Knowledge and skills will accumulate as students pass through the program. Although the individual programs of study produced for grades or courses may seem to stand alone, they should each be an interlocking piece of the larger K-12 curriculum. All parts should be essential to the attainment of the common long-term goal of scientific literacy. This can be achieved only if there is an interchange of ideas, plans, and information among teachers and administrators at all grade levels.

Plan a Science Curriculum with Local and Current Relevance

A K-12 science curriculum should make use of local resources, such as school forests, rivers, ponds, or power plants. Tying portions of the curriculum to local resources will involve the students in science experiences in their immediate surroundings and remove science from the abstract realm by providing concrete examples of the use of science.

Teachers should plan ways for students to discuss current events in science. Scientifically literate individuals must realize that science is an ongoing, viable, current operation. They must not be limited to a historical view that is locked in textbooks. Newspapers, magazines, television, movies, and field trips are helpful in bringing the reality of science to the classroom.

Provide Appropriate Course Offerings

Very few of the students who complete high school will become scientists or technologists, but all of them should be scientifically literate. It follows, then, that the emphasis on the knowledge base of the biological, physical, and earth sciences in traditional junior and senior high school courses should be reduced. Scientific literacy, as described in section 1 of this guide, results from a balanced treatment of all four components—not just knowledge.

Further, as discussed in section 2, the level of problem- solving and intellectual skills of most of the students who will take a given science course must match the level required by the course. The intellectual development of many high school students has not yet reached the formal operational level. Since most traditional secondary science courses require abstract thinking, many students cannot succeed in them.

It is essential that nontraditional courses be developed that have a content appropriate to the expected ability of most, if not all, of the students that will enroll in them. These courses must have a balance of all four components of science education and should relate to the common experience and interest of a broad spectrum of students.

Decrease Dependence on Science Textbooks

This curriculum planning guide should help teachers develop their own science units or courses of study. Appropriate courses or units will be organized around a unifying theme or themes. In particular, themes should make it possible to emphasize two or more of the four components of this curriculum model in each unit. The science program should allow students to learn by participating in laboratory activities. Activities should be included that require students to gather information from sources other than the textbook. A reduced emphasis on the textbook will allow more time for investigation and supplemental reading.

Provide Extensive Laboratory Experience at Each Grade Level

Hands-on laboratory experience is necessary at all grade levels to meet the intent of this guide. The nature of science education requires that problem-solving skills be developed from direct experience. When students are limited to studying written information or watching demonstrations where the results are already known, they cannot develop problem-solving skills. Similarly, electronic devices, no matter how sophisticated they may become, cannot replace needed direct experience.

There is another compelling reason for emphasizing the laboratory: even gifted students need laboratory experience to become confident in applying investigative skills. The science laboratory is instrumental in developing a wide range of individual competencies.

Options

The science curriculum is the delivery system by which the local school district provides overall direction and coordination to science teaching. The system can be so simple that is does nothing more than identify resources, usually textbooks, for given grade levels or courses. Or it can be so detailed that it gives teachers direction for every classroom activity from the initial presentation to evaluation.

To follow the intent in this guide, the science curriculum will incorporate

- the four components of science education;
- the 22 objectives within the four components;
- the eight stated recommendations.

The specific delivery system used by a school district is a matter of local choice. There are at least five options for local districts to use in implementing the recommendations in this guide. Each has advantages and disadvantages.

Option 1. Develop a Local Science Curriculum with Local Resources

A total local curriculum

This option assumes minimal dependence on other curricula or textbook organizations. It requires identifying objectives and the teaching activities to reach them and a considerable amount of writing and selection of supplementary resources. This option definitely requires cooperation and a well defined purpose as well as ongoing program evaluation and revision.

Advantages

- Teachers who develop their own curriculum usually implement it faithfully. A feeling of ownership leads to best use.
- A locally developed curriculum and related materials can best match the recommendations given in this guide.
- Full advantage may be taken of local resources and the interests and talents of both teachers and students.
- Involvement in curriculum development is one of the best methods for staff development. This outcome can justify high related costs.
- Developing a local science curriculum maximizes local control.

Note: Most of the outstanding science programs in the nation have been developed locally with minimal dependence on textbooks as organizers. This is demonstrated by programs selected by the Search for Excellence in Science Education conducted by the National Science Teachers Association.

Disadvantages

- Curriculum development is difficult. Some teachers lack the necessary experience and motivation.
- Small districts may lack a critical mass of science teachers. Curriculum development requires active and meaningful interaction of no fewer than three individuals with similar expertise.
- Local development requires a large investment of professional time, and, therefore, money. Effective curriculum development takes a great deal of time—weeks or months, not hours or days.

Note: Section 5 contains a description for a curriculum development process that will make local efforts as efficient as possible and reduce the disadvantages listed above.

Option 2. Adapt an Available Science Curriculum to Local Needs and Resources

The process of adaptation is similar whether the curriculum selected comes from another school system, a nonprofit agency such as the National Science Foundation (NSF), or a commercial source. It is necessary to establish what the adapted curriculum is intended to accomplish before selecting the program to be used. If this guide is used, the science program should be selected that best matches the guide's objectives and best implements its recommendations.

Adopt and adapt a curriculum developed elsewhere.

Advantages

- The time and effort necessary for curriculum development has been invested by the original developers.
- The curriculum to be adapted has been used in the classroom and has been evaluated over time.
- Only minor changes should be necessary to adapt a successful science curriculum to local needs.
- The science curriculum was selected because it implements many of the recommendations of this guide.
- The process of adaptation is less costly than original development.

Disadvantages

- The local staff does not know the selected curriculum first hand, nor feel ownership in it. Inservice training is essential for implementation.
- The selected curriculum probably does not meet all of the requirements of this guide nor all local needs. Adaptation may be difficult and the results imperfect.
- Costs for consultant services from the original project add to total costs.

Note: The same curriculum development process used for original development will be needed to evaluate other curricula for selection and to make necessary adaptations. See section 5.

Option 3. Evaluate and Modify the Existing Local Science Curriculum Using this Guide's Recommendations

Modify and improve what was done before.

In some school systems, extensive science curriculum work has been done in the past, and there is reason to believe that some, or most, of what is being done should be retained. In this case, the option chosen may be careful evaluation of the program with resulting modification to adjust for weaknesses.

Advantages

- *There is no need to reinvest the time and effort that went into the* original development.
- The existing curriculum probably meets local needs and uses local resources.
- The existing curriculum is known and understood by the staff. Hence, modification will be simplified.
- The process of evaluation and comparison to the model proposed in this guide will give credibility to the curriculum. Modifications will strengthen teacher confidence.

Disadvantages

- Often favorite activities in long existing programs are hard to give up. Teachers often have trouble taking an unbiased view of their curriculum.
- The staff will need extensive time to become familiar enough with the recommended model in this guide to use it in their grade-by-grade revisions.

Note: The process described in section 5 is useful in comparing the existing curriculum to the recommended model.

Option 4. Adopt a Commercially Available Laboratory-based Program

There are curriculum materials available from commercial sources that emphasize direct laboratory experiences. Some of these were initially developed with funds from the National Science Foundation. Others were developed by the companies that sell them. Some have textbooks associated with them, while some depend on teacher materials and supplementary reading material for students. The best of these programs were carefully done to include two or more of the components presented in this guide. They have been extensively evaluated and proven to be effective when properly implemented.

Buy a prepared total curriculum.

Advantages

- These programs are based on the same principles that led to the recommendations in this guide.
- These programs are highly validated. They produce positive outcomes in learning science as well as related subjects such as reading and mathematics. Abundant research shows that these programs work.
- Everything needed to implement these programs is available in complete packages that have been tested and improved over time.
- Laboratory-based programs have reduced emphasis on specific textbooks and, therefore, allow flexibility in adaptation. They tend to encourage reading of supplementary materials.

Disadvantages

- There is a need for staff training to implement these programs. Special training is also necessary for staff replacements.
- Management, maintenance, and replacement of equipment and materials is usually more difficult than with local development.
- Adaptation to an extensive model such as that presented in this guide is difficult without losing the intent of the original program.

Note: Even with the best commercial curricula there is a need to go through the process of curriculum evaluation and modification to meet the recommendations of this guide.

Option 5. Adopt Textbooks or a Textbook Series

Buy textbooks or a textbook series.

There is a large variety of science textbooks available, either as independent books for separate courses at the middle/junior and senior high school levels, or as textbook series for K-6 or middle/junior high school programs. They exist both with and without associated laboratory programs. Some can be purchased along with laboratory kits of equipment and consumable materials. Curriculum resources in this category are largely limited to an emphasis on the science knowledge component. Recommended laboratory activities are often only demonstrations of the facts and principle described in the text. Most are not particularly effective in teaching problem-solving skills.

Advantages

- A part of the organization for a curriculum is provided by the book or series of books. Recently published books will relate closely to one or more of the components of science education.
- A textbook fulfills a need that is often felt by teachers, students, and parents. Reading ability may be associated with the traditional use of textbooks.

Disadvantages

- Textbooks are designed for a wide market. There is no feeling of local ownership.
- Books, by their nature, emphasize descriptive information.
- Books must be applied only to the functions for which they are designed. The aspects of the science curriculum not met by textbooks must still be developed locally.
- There is a tendency to let the study of textbooks, once selected, become the focus for studying science.
- The cost of textbooks often consumes a disproportionate part of the science teaching budget. Use of the laboratory often suffers.

- Acquisition and maintenance of equipment and materials for a laboratory program to accompany textbooks is difficult.

Note: Selecting a text leaves a major part of the curriculum development process still to be done. In the best situation, textbooks should be purchased only after the curriculum framework and related criteria for textbook selection are established. Textbooks purchased in this way and used properly are a very important resource for science teaching.

Comparing Options

Each of the five options has advantages and disadvantages. All of them require considerable local effort to develop and implement a meaningful K-12 science curriculum. Purchasing power alone cannot create the ideal program; an effective science curriculum requires cooperation among all local teaching staff and strong administrative support. Deciding which option will be pursued is an important step in developing a science curriculum. In deciding, money should not be the major factor considered. Costs of the five options will be roughly equal if they are developed to the fullest extent. Individual costs among the options, however, do vary considerably for equipment, materials, books, and professional time.

A Process for Developing a Science Curriculum

5

Worksheets for Science Curriculum Development
Establishing Procedures
Identifying Themes
Identifying Learning Activities
Scheduling Learning Activities
Refining and Finalizing

Worksheets for Science Curriculum Development

The worksheets on the following pages provide a process for translating the recommendations set forth in this guide into practice. They are intended for use by individuals or small groups of teachers and curriculum planners to develop science curriculum materials consistent with the recommended model.

The worksheets involve a process which assumes that a K-12 science curriculum exists as a continuum of related parts, each associated with a particular grade level or course. Further, the worksheets assume such parts are organized into discrete subparts often referred to as units or modules of instruction (a "unit on insects" in elementary school, a "module on food" in middle/junior high school, or a "genetics unit" in a biology course). The worksheets are designed to guide the science curriculum development process at all such levels of organization.

Worksheet 1 is designed to establish parameters for all units of instruction at a particular grade level. It needs to be completed only once for a given level. Reference is not made on Worksheet 1 to particular science disciplines or subjects that are often the basis for high school science courses. However, the worksheets do apply to such courses as well as they do to interdisciplinary science courses.

Worksheet 2 is designed to identify topics which could serve as themes for units of instruction based on parameters established on Worksheet 1. Each topic identified on Worksheet 2 may be pursued for development using Worksheets 3 through 5. Following the process and format suggested in the worksheets assures consistency with recommendations for science education set forth in this guide.

Note: The explanations of Worksheets 3, 4, and 5 are followed by *format examples*, showing how a curriculum planner or teacher might write in information. Each format example is followed by a blank worksheet that can be copied and used in the curriculum development process. The format examples are intended only to clarify usage of the worksheets.

Establishing Parameters

PURPOSE: Establishing parameters for units of science instruction for a particular grade level (or course)

A. Indicate grade level or course. _______________

B. Refer to the recommendations in section 4 of this guide. Enter below the appropriate percentage of time allocated to each of the four components of science education. Use the appropriate percentages as shown in table 9, p. 28; for example, for fourth grade use grades 3-6 time allocations.

Component	**Percentage of Total Time**
1. Problem Solving	_________ %
2. Science Knowledge	_________ %
3. Nature of Science	_________ %
4. Science, Technology, and Society	_________ %
TOTAL	100%

C. Enter the number of minutes per week allocated for science instruction at this level. See tables 8 and 9, p. 27-28.

Minutes per week = _________

D. Calculate the following, using the percentages entered in item B and the minutes entered in item C.

1. Problem Solving—minutes to be allocated per week for this grade level. Multiply entry B(1) by entry C, divide answer by 100.

   Minutes per week = _________

2. Science Knowledge—minutes to be allocated per week for this grade level. Multiply entry B(2) by entry C, divide answer by 100.

   Minutes per week = _________

3. Nature of Science—minutes to be allocated per week for this grade level. Multiply entry B(3) by entry C, divide answer by 100.

   Minutes per week = _________

4. Science, Technology, and Science—minutes to be allocated per week for this grade level. Multiply entry B(4) by entry C, divide answer by 100.

Minutes per week = __________

Note: The above percentage time allocations are consistent with the guide's recommendations. Departures during part of a unit should be compensated during remaining time; the allocations may be regarded as weekly averages.

E. Review the section of the guide for the grade level which applies:
   K-2, section 8
   3-6, section 9
   Middle/Jr. High School, section 10
   Senior High School, section 11

F. Study the entire list of 22 objectives for science education (table 7, p. 22-23). Then, examine the specific objectives listed for the grade level in the guide. In the appropriate column in the following table enter the code number (e.g., 1.1) of each objective, according to the recommended degree of emphasis (high, medium, or low) given in the guide. Also enter weekly time allocations from item D in the appropriate column.

Objectives	**Time Allocations***	**Emphasis of Objectives**		
		High	**Medium**	**Low**
Problem Solving Objectives 1.1 - 1.4				
Science Knowledge Objectives 2.1 - 2.6				
Nature of Science Objectives 3.1 - 3.7				
Science, Technology, and Society Objectives 4.1 - 4.5				

***Enter minutes per week from item D.**

G. The information generated in Worksheet 1 provides parameters for all units to be developed at the grade level or course specified in item A. Item D specifies the amount of time to treat each of the four components of science education during a typical week of a unit. Item F relates time allocations to the specific objectives that are given relative emphases. While a single unit would probably not address all objectives of high importance, comprehensive treatment of objectives may be planned across several units.

Note: Save Worksheet 1 for reference in planning individual units using Worksheets 2 through 5.

Identifying Themes

PURPOSE: Identifying themes for units of science instruction

A. Refer to the table completed on Worksheet 1(F). Identify and review the objectives designated for high emphasis within the appropriate grade-level section of the guide. These are the targeted objectives for the science units to be developed; they should be visually available while working.

B. If the title or theme of a unit to be developed already is known or is dictated by some external condition, proceed directly to Worksheet 3. If not, continue to item C below.

C. Think of topics or themes that could serve as vehicles for pursuing selected high emphasis objectives identified on Worksheet 1(F). Comprehensiveness is not required; a given theme may serve only some objectives, while another theme serves others. Record on note paper those themes that seem richest in possibility for pursuing the greatest number of high emphasis objectives. Do not, at this stage, be concerned about details of time allocation, scheduling, etc. Use quick-ranging thinking (or, if working within a group, "brainstorming" discussion) to identify possible activities that could serve specific major objectives for each theme. Make notes on ideas using brief descriptors for activities such as "map school grounds," "metric cake recipe," "home garden soil samples," etc. The main idea is to generate a set of possible activities associated with several objectives in the context of each unifying theme.

Record themes that seem to have promise and save the notes for each.
Possible themes:

1.

2.

3.

4.

D. Each theme may be pursued for development into a unit using Worksheets 3 through 5.

Identifying Subobjectives and Learning Activities

PURPOSE: Identifying learning activities associated with high, medium, and low emphasis objectives and a chosen theme

Even though the themes were chosen on the basis of high emphasis objectives, it will be necessary to include subobjectives and activities for medium and low emphasis objectives as well. Only the emphasis will be different.

A. Enter the unit title or theme: ______________________________

B. Again review the objectives identified for high emphasis on Worksheet 1(F).

C. Enter objectives, subobjectives, and corresponding possible learning activities in the following format (*Learning Activity Table*). The table can be duplicated for this purpose. Developing subobjectives and teaching activities is a difficult task. See the examples given in the grade-level sections of the guide. Also, review the characteristics of students at each grade level before selecting subobjectives and related teaching activities. Apply the following meanings to column headings.

Subobjectives are specific objectives to be generated by the teacher, each of which contributes to a particular high, medium, or low emphasis objective (for example, subobjectives 1.11, 1.12, 1.13 contribute to high emphasis objective 1.1). (See grade-level examples.)

Learning Activities are activities that contribute to one or more particular subobjective (for example, activities 1.111 and 1.112 contribute to subobjective 1.11).

Try to provide at least two learning activities in different modes for each subobjective. Use code numbers and abbreviate statements of objectives and learning activities when making entries in the *Learning Activity Table*. Do not yet be concerned about form or scheduling; this is only an expanded form of the initial brainstorming used with Worksheet 2. After initially selecting activities, review them again to assure that they are appropriate for the expected problem-solving and intellectual abilities of the intended students.

Note: The form for Worksheet 3 is essentially the same as the format that has been used for all of the grade-level examples given for the four science curriculum components in sections 8-11. The format example on p. 43 shows a method for completing the worksheet on p. 44. Make as many copies of that worksheet as are needed to develop subobjectives and activities for the unit or module.

Format Example: Learning Activity Table

High Emphasis

1.1 Objective: Ask questions. The student shall ask answerable questions about nature.

Subobjectives		Activities	
1.11	Noting patterns. The student shall see relationships among objects and events.	1.111	Note similarities in a set of objects (e.g., all dogs have fur, all fish are in water, all rocks are hard).
		1.112	Note similarities in events (e.g., each day the sun rises and sets, thrown objects always fall to the ground.
1.12	Noting discrepant events. The student shall note exceptions to patterns.	1.121	
1.13		1.131	
		1.132	
		1.133	

1.2 Objective: Collect data. The student shall collect pertinent data from nature.

1.21	Observing. The student shall make accurate observations of objects and events using the senses or using instruments to aid the senses.	1.211	Distinguish differences in physical properties of objects by direct observation.
		1.212	Manipulate or change an object in order to expose its properties for observation.
		1.213	
		1.214	
1.22	Measuring and quantifying. The student shall order by magnitude of measurable characteristics.	1.221	
		1.222	
		1.223	

Medium Emphasis

1.3 Objective: Analyze data. The student shall analyze data.

1.31	Predicting. The student shall use observations already made to predict new observations.	1.311	Use the observed taste of three pieces of apple to predict the taste of a fourth piece.
		1.312	
1.32		1.321	

Learning Activity Table

______________ **Emphasis**
(High, Medium, or Low)

________ **Objective:** ____
Code No. (See statement in guide.)

Subobjectives	Activities
Code No.	Code No.

Worksheet 4

Scheduling Learning Activities

PURPOSE: Scheduling learning activities for a unit of science instruction

A. Specify the number of weeks for which the unit is to last:

Weeks = ________

B. Review the time allocations for high emphasis objectives on Worksheet 1(F). With the time allocations in mind, outline a probable schedule of activities for the unit, using the ***Learning Activity Table*** **(Worksheet 3) and the format example shown below.** The blank ***Learning Activities Scheduling Table*** **on p. 46 may be duplicated and entries made on it. Make as many copies of that worksheet as are needed to schedule completely the activities for the unit or module. As before, abbreviated descriptors may be used; final form will come later. When the** ***Learning Activities Scheduling Table*** **has been completed, proceed to Worksheet 5.**

Format Example: Learning Activities Scheduling Table

Week	Day	Activities by Code	Notes
1	1	1.112	
	2	1.221, 3.211	
	3	4.412, 2.122	
	4	3.111	
	5	1.111, 1.113, 1.114	
2	1	2.121	
	2	3.113	
	3	4.111, 3.112	
	4		
	5		
3	1		
	2		
	3		
	4		
	5		
4	1		
	2		
	3		
	4		
	5		
5	1		
	2		
	3		
	4		
	5		

Learning Activities Scheduling Table

Week	Day	Activities by Code	Notes

Refining And Finalizing

PURPOSE: Refining and finalizing a unit of science instruction

A. Estimate the time required for each learning activity listed in the *Learning Activities Scheduling Table* (Worksheet 4). Total the estimated time to be allocated to activities associated with major objectives in each of the four components (problem solving; science knowledge; nature of science; and science, technology, and society). That is, total the times estimated for all activities having a code number beginning with number 1 (problem solving), number 2 (science knowledge), etc. Express each total as a percentage of the grand total of time allocated for the entire unit.

B. Compare the result of the above calculations with the recommended time allocations for high emphasis objectives on Worksheet 1(F). If obvious discrepancies exist, try to adjust allocations within the unit, or plan to compensate for these discrepancies in other units.

C. Make a note in the table on Worksheet 1(F) to indicate high emphasis objectives treated in this unit. Other units will be designed to pursue untreated objectives.

D. Review the objectives designated on Worksheet 1(F) for medium and low emphasis. Where it would be natural or implicit to include treatment of such objectives within this unit without disrupting planning already accomplished, add such objectives to the planning tables and note treatment of them on Worksheet 1(F).

E. The *Learning Activities Scheduling Table* now needs to be translated into a day-by-day set of plans for the teacher. *The Daily Planning Table* on p. 50-51 may be duplicated for that purpose. Adhere to the following directions for completing the *Daily Planning Table* (see format example on p. 48-49).

1. Complete the activities column first, listing activities by code numbers and appropriate descriptive words or phrases in the sequence in which the activities will occur.

2. List the objective(s) and subobjective(s) associated with the activity in the two columns provided.

    a. The code number and statement of each objective may be taken directly from the guide. These numbers have already been recorded in Worksheet 3, but probably in a different order.

    b. Each subobjective should be listed by code number and stated in behavioral terms by the teacher.

3. Make an entry in the time column for the number of minutes expected to be allocated to each activity.

4. List the instructional materials needed for each learning activity in the materials column.

5. Make notations in the final column.

Completion of the *Daily Planning Table* should provide sufficient direction for trial teaching. Trial teaching will provide needed information for evaluating the unit or module.

Format Example: Daily Planning Table

Week (*Circle*): 1 2 3 [✓ 4] 5 6 7 8 9 10

Day (*Circle*): 1 2 [✓ 3] 4 5

Unit Title Life Continues

Component objective		Subobjectives		Learning activities in sequence to be taught	
Code No.	**Identifier**	**Code No.**	**Statement by teacher**	**Code No.**	**Description by teacher**
2.2	Change	2.21	As living things grow they change in form and activity.	2.213	Observe the metamorphosis of meal worms.
1.2	Gather data	1.21	Observing	1.211	Describe daily changes in a population of meal worms kept in an oatmeal medium.
2.1	Diversity	2.14		2.142	

Time (min.) per activity	Materials per activity	Teacher notes
14 min.	Glass container, oatmeal meal worm culture	Meal worms can be purchased from Jones and Smith Supply Co. Oatmeal is in biology storeroom. Changes should be systematic. Adult beetles should be removed as they emerge.
10 min.	Magnifying glasses; charts indicating day, hour, condition of specimen, new observation	

Daily Planning Table

Week (*Circle*): 1 2 3 4 5 6 7 8 9 10

Day (*Circle*): 1 2 3 4 5

Unit Title ________________________________

Component objective		**Subobjectives**		**Learning activities in sequence to be taught**	
Code No.	**Identifier**	**Code No.**	**Statement by teacher**	**Code No.**	**Description by teacher**

Time (min.) per activity	Materials per activity	Teacher notes

Evaluating Students and Programs

6

Need for Evaluation
Evaluation of the Four Science Curriculum Components
Test and Item Quality

Need for Evaluation

A Guide to Curriculum Planning in Science calls for major shifts in emphases in the school science curriculum, away from programs that stress the acquisition of factual knowledge and toward a balanced program with appropriate emphases on the four components of science education at specific grade levels. Each of these components—problem solving, science knowledge, nature of science, and science, technology, and society—requires adequate evaluation.

Science and technology are self-correcting. New knowledge and its applications are repeatedly tested. Like science and technology, the school science curriculum must be self-correcting. That is, the curriculum must have a built-in feedback system so teachers and administrators readily know the parts that work, the parts that are inappropriate to the student's characteristics, and the parts that do not lead to the objectives and need immediate repair.

The curriculum must have a built-in feedback system so teachers and administrators readily know the parts that work. . . .

Evaluation is a process for determining if expectations are being met. Teachers continually evaluate how well individual students are achieving the science curriculum objectives. Evaluation has traditionally been limited to testing students for grading purposes. But teachers also need to examine the effectiveness of the overall curriculum, teaching methods, texts, and library and laboratory materials. Teachers often do not feel competent in formal program evaluation. Many need to develop a sense of the importance of program evaluation as a means of knowing the curriculum changes that are needed to improve teaching and learning.

Teachers needing to improve their evaluation skills should divide evaluation concerns into those focusing on student learning outcomes and those focusing on the quality of the science program. Table 10 is a brief summary of concerns pertaining to student and program evaluation. Evaluation details specific to each grade level are given in sections 8-11.

Evaluation Process

Why Evaluate?

Students. Evaluation provides feedback to the teacher to document individual student learning progress and alerts teachers to instances where the desired learning has not occurred so that alternate or supplemental learning activities can be provided. It also helps students know their own progress and problems. Student evaluation, of course, makes student grading possible.

Science Programs. Science programs, no matter how well designed, should always be subject to evaluation and change. New discoveries in science and technology, changing social needs, and changing student needs necessitate periodic review and updating of all science programs. Evaluation provides a sound basis for revision and improvement.

Who Evaluates?

Students. The student, teacher, and principal are all responsible for learning and so must also be responsible for evaluation. The teacher directs the learning and the evaluation.

Science Programs. K-12 science programs are district programs; their evaluation should be undertaken by a team or task force appointed by the administration and/or school board. The task force will receive information and be responsible for acting on it. Teachers must be involved in data collection and interpretation, as well as in drafting the recommendations for change. On a smaller scale, individual teachers can accumulate student data to evaluate effectiveness of their portion of the total science curriculum.

What is Evaluated?

Students. Evaluation must cover all learning outcomes associated with the four science education components. Testing should relate to all objectives in all components and not be limited just to science knowledge objectives.

Evaluation Process

Science Programs. Everything associated with the science program should be evaluated, including student learning outcomes, facilities, resources, and adequacy of the program to meet the needs of students. Evaluation should focus on the effectiveness of classroom and laboratory activities to reach established objectives.

How to Evaluate?

Students. Problem-solving competence is best observed in the laboratory via tasks completed, data analyzed, graphed, or otherwise displayed and interpreted. Progress in all four components may be judged not only by paper-and-pencil tests but through class discussion and evidence that skills and knowledge are being correctly applied. Levels of application should always be considered when devising measurement strategies.

Science Programs. Group measures rather than individual tests are easily summarized and facilitate comparisons with other groups. Goals of district science programs should be explicitly stated and measures should be designed to obtain information to demonstrate whether the programs are meeting the goals.

When to Evaluate?

Students. While formal written evaluation may be scheduled at the end of a unit or module, informal observation and judgment of performance should occur on a daily basis. A checklist can provide a record of what has been learned.

Science Programs. Program evaluation, like student evaluation, is an ongoing process. However, systematic data collection and analysis should be scheduled at least annually, with major review conducted every five years.

Evaluating Science Programs

Program evaluation is a process of systematically and continuously monitoring the progress of a program and the program's effects on teachers and students. Initial evaluation should be a needs assessment or evaluation of the current program; this provides a basis for setting priorities and goals for program improvement. This guide may be used to establish criteria for the desired program. As the program is changed to meet the established priorities and goals, periodic informal or formal evaluation should be done to check on the effectiveness and expected consequences of the changes. These formative checks will provide further direction for program development as ideas are tried, expanded, or discarded.

Initial evaluation should be a needs assessment or evaluation of the current program . . . .

Following full implementation of the new science program, a formal summative evaluation should be conducted to measure the extent to which the established goals are being met. Data from this evaluation can be compared to data from the needs assessment to show the effects of changes in the science curriculum. The data also indicate direction for further program development, since instructional improvement, like evaluation, should be a continuous, systematic process. Evaluation serves as a management plan for program development. Evaluation provides data for making informed decisions about program improvement.

Evaluation serves as a management plan for program development.

Standardized tests are frequently used as group measures in program evaluation, and allow comparisons with other districts or regions. This procedure is useful, but the results must be interpreted with caution. Most of the published tests are weak in measuring the science curriculum components of problem solving, the nature of science, and science, technology, and society. Since standardized test scores are heavily weighted for science knowledge, additional measures should be used to evaluate the total curriculum. Also, most standardized measures yield little information about the individual student's progress. Rather, these tests provide a snapshot of what learning exists for a group of students on a given day; therefore, the scores must be interpreted in the proper context.

Other forms of evaluation useful in program review include: student impressions of the effectiveness of instruction, evaluating written materials, evaluating teaching methods, and evaluating laboratory procedures. Measuring these and other curriculum components provide a basis for program evaluation.

An innovative program designed to meet the needs of students in a contemporary society requires equally innovative evaluation procedures that follow students through their schooling, provide information on student achievement in courses, and test the validity of the curricular content against contemporary measures of what is considered important in science education. In most districts, there is no provision for giving teachers and curriculum designers access to long-term student data. Districts should establish a plan for the systematic collection of evaluation data in a format that will allow for long-term review of the effectiveness of their science programs.

Evaluating Student Progress

The school science program is not only a sequence of courses, nor is its only purpose to prepare students who want to major in science in college. The central purpose of the science curriculum is to develop scientifically and technologically literate students (see section 1). This is achieved through appropriate teaching and learning in the four components of science education. The central purpose of student evaluation is to measure how well students are achieving the objectives and subobjectives identified for those components.

Student evaluation is a means of providing feedback to the teacher and student on the effectiveness of the learning process. It is useful to think of three different types of evaluation.

Diagnostic evaluation may be used before instruction begins to provide the teacher with a measure of what has already been learned. A pretest should be used to modify the instructional process or rate of instruction. Diagnostic tests can also be a basis for choosing proper alternative activities for individuals.

Formative evaluation is the ongoing evaluation of the learning process which provides feedback to the teacher on student progress, and, similarly, provides feedback to the student as a form of reinforcement.

Summative evaluation, as the term implies, provides the teacher with an end-of-unit or end-of-course sampling of what has been learned, and provides a partial basis for assigning the grade. It also provides indications of a level of achievement.

Limitations

It should be remembered that any evaluation method is at best a sample of the learning that has taken place. Quickly designed or borrowed tests usually do not measure what is considered important to learning, but merely test students' recall of obscure details. Such tests do not measure students' comprehension of major concepts and probably yield false measures of achievement.

Many teachers think of evaluation as paper-and-pencil tests consisting of multiple-choice, true/false, or essay items. Such tests are often limited to measuring the acquisition of knowledge and seldom measure performance. Any paper-and-pencil test is a limited collection of items selected to sample what has been learned. If the sample is biased or not representative of what is considered important, the science test scores will be a reflection of that bias and will not be a valid indication of meeting the major objectives.

Methods

Multiple-choice items consist of a statement or question followed by a correct response or answer and a series of foils, or incorrect answers. Foils should be logically possible and grammatically consistent with the statement or stem. A serious defect occurs when the statement or the correct response is ambiguous, contains more than one issue, or is grammatically flawed. Good multiple-choice items are difficult to write and usually require trial testing and modification to be reliable measures of learning.

Although written tests will always be an important part of student evaluation, it is essential to supplement them with other kinds of observations. Often teachers hesitate to use subjective judgments of student performance because such methods do not yield numeric scores which can be easily defended. However, so-called objective tests require professional judgment in their construction and administration; teachers must use subjective methods requiring knowledge and experience which cannot be free of bias. It follows that subjective judgment of student performance—class participation, quality of questions, evidence of successful homework and reading—can, when observed systematically, be as valid for evaluating students as written tests. This is especially true in evaluating problem-solving competence when it is necessary to eliminate unrelated factors that appear in written tests such as reading ability, use of terminology, and test anxiety. A combination of observations, including responses on written tests, is clearly the best way to accomplish comprehensive student evaluation.

Subjective judgment of student performance can be as valid for evaluating students as written tests.

Evaluation of the Four Science Curriculum Components

Problem Solving

The science laboratory provides a powerful means for teaching problem-solving skills and it is the best place for evaluating progress in developing problem-solving skills. Teachers need to distinguish between a student's ability to demonstrate a skill, such as measuring the length of an object, and the student's verbal ability to respond to a question or correctly answer a paper-and-pencil test item on measurement. Both are important, but the ability to engage in problem-solving activities is direct evidence of the student achieving the necessary skill.

Problem-solving skills are best observed and evaluated with a student "in action." A checklist calling for the teacher's judgment of student performance in problem-solving skills will yield reliable information, which in turn can be used to guide or reinforce learning. A sample general checklist follows.

Problem-solving skills are best observed and evaluated with a student "in action."

This form can be expanded to include the subobjectives and process components that are included in a learning activity or unit. The same coding system used in the worksheets and in the grade-level sections of this guide can be utilized.

Sample

Problem-Solving Skills Checklist

		Performance		
		Superior	Acceptable	Unacceptable
1.1	**Ask Questions.** Does the student ask answerable questions?	☐	☐	☐
1.2	**Collect Data.** Does the student know what data are and demonstrate ability in collecting reliable information?	☐	☐	☐
1.3	**Analyze Data.** Can the student recognize patterns in information and organize the information so it is understandable?	☐	☐	☐
1.4	**Explain.** Can the student explain how the information was collected, what it means, and how it can best be analyzed to provide answers to questions?	☐	☐	☐

Teachers also can set up checklists for students as they achieve specific skills. These lists can be keyed to identify all of the students in a group who at a given time have or have not achieved a certain skill. Another method is to develop scoring sheets for students as they participate in laboratory activities. An example of such a sheet follows.

The columns can be changed to suit any situation or grade level. As problem-solving skills become more complicated, it is necessary for teachers to look for more detail in student performance.

■ Sample

Evaluation for Laboratory Activities

Student Name:

Laboratory Activity	Set Up Activities	Data Collection and Recording Activities	Analysis and Interpretation of Events and Data	Write up, Including Conclusions	Overall Laboratory Work Patterns
A					
B					
C					
D					
E					

5 = Superior, 4 = Good, 3 = Adequate, 2 = Needs Help at Every Step, 1 = No Progress.

Science Knowledge

Evaluation of science knowledge outcomes has been the traditional focus of most paper-and-pencil tests used in schools. Unfortunately, questions that call for simple recall of factual information do not indicate student understanding of major concepts. Higher level questions that call for the application or analysis of information should be constructed. This guide presents a model of six conceptual organizers which greatly facilitate learning and evaluation. (See the six objectives for this component.) For example, what should a student learn and what should be evaluated in a unit on permanent magnets and electromagnetism? Questions focusing on interaction and change can test the student's understanding of these concepts, not just the facts of magnetism. Evaluation efforts should focus on these concepts rather than on the recall of facts which are quickly forgotten. Results from such testing allow the teacher to advise students on their progress in developing a workable knowledge of interactions using magnets. Magnets and magnetism then become a means of teaching a larger concept. Many resources exist to aid teachers in evaluating science knowledge.

Questions that call for simple recall of factual information do not indicate student understanding of major concepts.

Nature of Science

The nature of science has traditionally received little attention in school science programs, except for occasional comment in teacher guides. Although this guide recommends that this component should not receive high emphasis until the middle/junior high school level, it is included at all levels, and, therefore, warrants evaluation across levels. Since understanding the nature of science is largely a matter of learning concepts, tests like those used to measure understanding of the science knowledge component can be used. However, especially at early levels, student par-

... student participation in discussion and responses to historical or current events in science indicate whether concepts are being retained and used.

ticipation in discussion and responses to historical or current events in science indicate whether concepts are being retained and used. Student behaviors and practices in laboratory situations can be observed to see if they are applying their knowledge of the nature of science. That is, are they concerned with accuracy of data? Do they report results without trying to make their observations meet their expectations? Can they criticize their own work as well as that of others as scientists would?

In any evaluation of the nature of science component, the seven identified objectives and related subobjectives should be the basis for observation or testing. For student evaluation, measures of this component should be weighted according to the relative emphasis it is given in the curriculum. For program evaluation, each activity designed to teach the nature of science should be carefully studied at every grade level to see if student achievement is as good as anticipated. In particular, do the activities match the characteristics of the students for whom they are designed? Evaluation for this component should be incorporated in the science program. Traditionally, the nature of science has been neglected in teaching and overlooked in evaluation; teachers have to make a conscious effort to break with that tradition.

Science, Technology, and Society

Instruction in science, technology, and society requires relating science to other subjects in the total school curriculum, as well as to the student's social perspective and personal life. This component of the curriculum integrates science with the entire school curriculum. To evaluate student learning in this component, questions in discussions or paper-and-pencil tests can ask students to demonstrate an understanding of how science and technology are related to their personal lives, community, state, country, and world. Students should use their knowledge of science and technology to analyze the impacts of these human activities on themselves and society. Evaluation procedures should require that students demonstrate the ability to analyze specific science, technology, and society interactions; this calls for students to respond to questions about society's reaction to scientific or technological developments, the political and economic costs, and the benefits that developments may have. In virtually every aspect of science, the connection with personal and social settings can be included and evaluated.

Evaluation procedures should require that students demonstrate the ability to analyze specific science, technology, and society interactions.

Evaluation of acquired attitudes and values requires special attention. It has been argued that science programs should avoid attitude and value issues. Considering that science and technology permeate almost every part of our lives, it is inappropriate and, indeed, impossible to avoid these issues. The teacher should openly address values and attitude issues, and the student's ability to respond to these issues should be measured. For example, science gives us new knowledge about the origin of disease, and new technology makes the possible transplanting of human organs, bone, and tissue. Society needs to develop policies on the wise use of these procedures. Evaluation of what the student is learning about these developments does not require precise or expected answers, but rather that the student can correctly and adequately use information to analyze the impact of the scientific and technological developments, and express opinions about the issues raised. Evaluation of this component should focus on the process students use to apply knowledge of scientific and technological information to decision making.

Test and Item Quality

Testing Definitions

It is important to examine the effectiveness of each evaluation procedure. It is especially important to assess paper-and-pencil testing, such as multiple choice, true/false, or completion items.

Difficulty of test items should be matched to the ability and achievement levels of the students. Difficulty is defined by the proportion of students who choose a correct answer for a given item. In a well constructed test, very few students should correctly answer all items, but essentially all students should be able to answer some of the items. An item that is correctly answered by 50 to 80 percent of students has a reasonable level of difficulty. An item that every student misses is useless; an item that every student answers correctly indicates that the item was successfully taught. Such items do not discriminate. It is a good practice to design tests to have items with a range of difficulty from very difficult (10 percent) to easy (90 percent).

Validity is a term used to describe the effectiveness of tests or individual test items in measuring the understandings or skills they are designed to measure. Although statistical methods can be used to determine validity, a subjective judgment of validity—called face validity—can be used. If an item or test score indicates that students have mastered a particular topic or skill which is necessary for subsequent learning, and if these students later demonstrate they are unable to proceed, a teacher may suspect the test was not a valid measure of their abilities.

Discrimination is the ability of a test to separate students who have mastered the concept or skill from those who have not. For a test to discriminate, the individual items must also discriminate. A simple but effective way of assessing item discrimination is the "high-low" technique. After the tests have been scored and the grades assigned, the test papers can be ranked high to low. The top students' tests, perhaps the top 30 percent, are selected and the responses summarized for each item. Similarly, responses for the bottom 30 percent of the exams are summarized. Following is such a summary for two test items, each with four foils. The correct responses are in bold type.

■ Sample

Test Item Discrimination

Item Number	Low Grades	High Grades
Item 1		
A	70%	10%
B (correct)	10%	80%
C	20%	10%
D	0%	0%
Item 2		
A	0%	5%
B	5%	75%
C	5%	15%
D (correct)	90%	5%

From this simple analysis, it is clear that item 1 does discriminate. That is, the students who scored high on the test did very well in that particular item, whereas the students who did poorly on the test tended to miss the item. Foil A was very attractive to the students who scored low on the test, but was not a particularly attractive item for the students who did well. Foil D appears not to work with either group, and should be carefully examined if the item is to be used again. Item 2 creates a very different situation. Only 5 percent of the students who did well on the test correctly answered this item, whereas 90 percent of the students who had a low grade on the test chose the correct item. The item discriminates, but in the wrong direction. It is defective and should be eliminated or completely revised, and the underlying false learning exhibited by the "low-scoring" group examined to find the cause.

Score Distribution

Some teachers expect all test scores to fall into a normal distribution, meaning that the same number will fall above and below the median or average score. Actually, normal distributions can be expected only when there is a random selection of individuals from a large total population. In the usual classroom, students are not randomly selected; they come from homes in the area served by the school district. Classes may have enrollments determined by special factors, such as athletics or activities that occupy students' time during particular class hours. The nature of elective science classes influences student enrollment. Generally, only students who like science and have done well in science courses will enroll in physics or other advanced science courses; consequently, the test score distribution is usually well above the median for all students. Therefore, grades should be adjusted upward. Not making this adjustment often results in low enrollments and reduces the effectiveness of the upper level science program.

Current and Future Issues in Science Education

7

Context for [illegible]
[illegible]
Integrating Science in the [illegible]
Computers [illegible]
[illegible]
Equity in [illegible]

Context for Teaching Science

The science curriculum is one part of the school curriculum; the school curriculum is only one of the influences acting on students. The total context in which the science program exists underlies the design of the curriculum, the materials, and the teaching methods. School subjects need to be coordinated so students have a comprehensive education. No one subject is more important than others, and all subjects should be taught so that they make the greatest contribution possible to general education. Science makes its most significant contribution to the school program when it is related to the experiences and responsibilities students have both in and out of school.

A variety of topics will arise in the process of teaching science because its subject matter extends into all areas of life. Some of these topics are controversial, especially those in teaching the science, technology, and society component of the science curriculum. Teachers are often surprised to find controversy in topics that seem to be without social conflict. But because of diverse social, economic, and religious backgrounds among individuals, an equal diversity in values and opinions among students can be expected. Teachers can follow a general rule: Avoid, as much as possible, any kind of indoctrination. Teachers' behavior, curriculum plans, and teaching resources should be as free of bias as possible. They need to try to allow for cultural differences among students, and, above all, show respect for a student's strongly held beliefs and commitments.

. . . choosing issues for the curriculum because they are controversial is not as good a criterion as choosing issues because they contribute to objectives.

Controversial issues should not necessarily be avoided, but choosing issues for the curriculum because they are controversial is not as good a criterion as choosing issues because they contribute to objectives or subobjectives that have been identified. Controversy can be a good motivational device, but teachers need to use good judgment to avoid putting unnecessary stress on students, as well as to avoid discrediting an otherwise successful program.

K-6 Instructional Time Allocations

In order to assure a balance among subjects in the elementary grades, the entire instructional program should be viewed as a whole. Then the available instructional time should be allocated so that all subjects receive appropriate attention. This task was undertaken by Wisconsin Department of Public Instruction staff; recommendations for minimum time allocations for eight major K-6 subject areas are shown in table 11. In addition to the instructional time devoted each week to science instruction, science can be effectively integrated with other subjects in the curriculum.

Table 11

Minimum Allocated Instructional Time: Recommended by the Wisconsin Department of Public Instruction*

Grades K-6: minutes per week for a six-hour instructional day

Grade Level	K**	1	2	3	4	5	6
Reading/English Language Arts***	30%	700	700	600	600	500	425
Mathematics	10%	250	250	250	250	250	250
Social Studies	10%	125	150	175	200	225	250
Science	10%	100	100	150	150	175	250
Health	10%	75	75	100	100	125	125
Physical Education	10%	150	150	150	150	150	150
Art	10%	90	90	90	90	90	90
Music	10%	75	75	75	75	75	75
Foreign Language	---	---	---	---	---	100	100
Environmental Education****	****	****	****	****	****	****	****
Total Allocated Instructional Minutes		1565	1590	1590	1615	1690	1715

* While there is a recommended allocated instructional time for each subject, educators are encouraged to integrate subjects within the curriculum whenever possible.

** Up to one-third of each day in the kindergarten schedule may be reserved for students' self-selected instructional activities. The allocated instructional time recommendations presented in column K apply only to the portion of the schedule planned for teacher-directed activities. The time allocations for kindergarten are expressed in percentages to facilitate planning for various kindergarten schedules.

*** Instruction specifically designed to strengthen reading and writing abilities should be integrated with other disciplines, e.g., health, science, and social studies. For further discussion of the recommendations, see *A Guide to Curriculum Planning in Reading* and *A Guide to Curriculum Planning in English Language Arts*.

**** Environmental topics should be infused into instructional units in all subjects, with the greatest emphasis in health, science, and social studies. A significant amount of time should be devoted to such topics. For a further discussion of this recommendation, see *A Guide to Curriculum Planning in Environmental Education*.

Integrating Science in the Total Curriculum

Reading Skills

Reading should be an important activity in studying science. Not only is reading a source of information of all kinds for the science student, but science is a curricular area in which reading proficiency can be developed.

The Directed Reading Thinking Activity (DRTA) is a general model for teaching subject-area reading that applies much of the appropriate knowledge and recent research regarding reading comprehension instruction. DRTA is described in detail in *A Guide to Curriculum Planning in Reading*, which should be consulted for a more complete description of the activity. DRTA provides an instructional framework for integrating specific reading strategies into studying science content, while encouraging development of critical reading and thinking that can be applied to all subject areas. The five DRTA stages are described below, with suggestions for applications by science teachers.

Preparation

Preparation for Reading. Before giving a reading assignment, teachers should examine the selection or text to determine factors to help students comprehend and to identify unfamiliar vocabulary and concepts. Next, teachers should assess students' backgrounds to decide whether they have the necessary laboratory experience, concepts, and vocabulary to get satisfactory meaning from the text. If the background is insufficient, it will be necessary to supplement or change the reading selection. Focusing on concepts and meanings in familiar contexts is more beneficial to learning than a rote learning of new words in isolation. Unfamiliar vocabulary essential to understanding text material should be taught before and during reading in the context of relevant and interesting settings.

Setting a Purpose. The more thoroughly teachers prepare students to understand the organization of a text, the more likely students are to comprehend it. Before reading a selection, students should preview it, examining its arrangement and features such as headings, italicized words, and summary statements. Through this procedure students begin to perceive a purpose for their reading. The teacher should direct students' attention to important concepts contained in the text. For example, an earth science teacher who wants students to understand the concepts of uplifting and faulting should point out which major causes the text will focus on, such as subduction and plate motion.

Reading

Guided Silent Reading. With reading purposes clearly in mind, students should be allowed to read the material silently at their individual pace. To promote effective reading, students should be given definite guidelines (questions, outlines, charts) to refer to while reading. Also, structured overviews of material should be used focusing on main ideas and key facts.

Discussion, Rereading, and Reflection. The reading content is discussed after guided silent reading. If students have read independently, they should have a chance to tell one or more of their peers what they have read and how it met their purposes for reading. They should decide whether the information they acquired was sufficient for understanding, raising new questions, or leading to meaningful laboratory investigations.

Application

Critical Thinking. Students should be encouraged to ask questions that go beyond the specific details of the text. They should think critically about the overall concepts in the text. Where appropriate, they should raise questions that can be investigated. Often it will be necessary to reread sections or passages to support interpretations or to identify discrepant understandings. Rereading should always have a definite purpose.

Extension Activities. Extension activities serve to expand on information gained from reading. In science, these activities are often carried out in the laboratory or in the field. Such activities serve many purposes, but in relation to reading they reinforce new ideas and information and help to expand general understanding. Reading used in this way becomes essential to achieving objectives for the problem-solving component, while at the same time contributing to reading competence.

Writing Skills

Writing can be used in many ways to support learning in science. When students write, they must make active individual attempts to produce meaningful statements after contemplating concepts. Writing requires planning and reviewing, and helps students to connect prior knowledge with new information. It also exposes students thought processes for teacher evaluation.

In science education, writing is an essential skill related to problem-solving. Although there are many ways to make explanations, the written report that includes graphics as well as written narrative is essential to complete investigations. The following recommendations are intended to help science teachers make better use of writing as a classroom tool and help students become more effective writers. Teachers should

- think of writing as a tool to aid in learning and as a means of communication, not only as a means of evaluation.
- assign frequent, short assignments rather than a single long one. Repeated practice is important in learning writing, as in learning any skill.

- be clear in expressing the purpose of a writing assignment. Written assignment sheets specific to each assignment provide guidance through the writing process and answer many questions in students' minds.
- provide ample time and opportunity for students to brainstorm and explore ideas in major writing assignments, and allow them to develop their ideas through several drafts.
- assign some writing that will not be evaluated. Idea logs, notebooks, summaries, and brief writings to clarify concepts serve a more useful purpose if they are viewed as means, not ends.
- provide feedback as students produce drafts rather than saving all feedback for the final evaluation, giving students opportunities to apply teacher suggestions.
- provide opportunities for students to talk about what they are writing. Mini-conferences and small student groups can be used to provide feedback during the writing process. Oral comments are faster and, often, more effective than written ones.
- pay attention to strengths as well as weaknesses. Success breeds success.
- share successful student writing with the class by reading aloud, mounting papers on bulletin boards, and using the overhead projector.
- focus on one or two concerns at a time. Attention can be given to ideas and organization first, then mechanical correctness. Students cannot be expected to attend to everything at once.

Mathematics

It is common for curriculum planners to attempt to integrate the teaching of science and the teaching of mathematics. This is natural because of the dependence of science on quantitative data and on mathematical descriptions or formulas. Much of the theoretical work done in science is almost completely mathematical proof and derivation. However, it is important to understand that mathematics is not just a tool for studying science, and that the natural phenomena of science provide the mathematical applications that students need to learn and understand mathematics. Science teachers should expect to help students to use mathematics effectively and, when necessary, they should actually teach the mathematics needed to work with areas of science instruction. This is especially true in the senior high school, where specialized techniques are used, such as vector analysis and application of trigonometric functions and logarithms.

When students use mathematics in science, they should learn to solve problems systematically. It is not enough to get an answer; the process by which the problem is solved should always be clear. If there is any derivation from standard formulas or equations, the steps by which that derivation is made should be given in sequence. When numerical data are introduced, the sources of those data should be indicated.

Mathematics is an important part of the explanation process. The use of graphs and charts is based on mathematical analysis. The combination of mathematics and writing is essential to reporting the results of investigations.

Social Studies

The science curriculum recommended in this guide places a heavier emphasis on the human or societal aspect of science than has been traditional. The relationship between science and social studies is intended to be much closer than it has been in the past. *A Guide to Curriculum Planning in Social Studies* and this guide make extensive reference to teaching the interactions of science, technology, and society.

The problem-solving skills as described in this guide closely correlate with the skills taught through the social studies. In addition, it has been recommended at both the national and the state level that there be an integrated science and social studies course at the senior high school level to provide in-depth study of problems and issues that result from the interaction of science, technology, and society.

This guide's recommendations require science teachers to use many of the same teaching strategies that social studies teachers commonly use. This is true for all four of the science curriculum components with the possible exception of science knowledge. For this reason, science curriculum planners should become very familiar with the social studies curriculum in order to coordinate study in the two subject areas. Science and social studies include the study of all possible phenomena, from the most concrete physical phenomena to the most abstract historical phenomena. The close relationship between the two areas must be kept in mind when planning curriculum in each.

Environmental Education

Confusion often occurs about the nature of environmental education and its relationship to science. At times environmental education is treated as a specialized area of science. Perhaps this happens because scientists study environmental effects, or because the scientific word "ecology" is often taken to be synonymous with environmental education. Actually, environmental education has a relationship with many if not all subject areas, and is best taught when it is integrated with other subjects. Science, like other subjects, can make a major contribution to students' understanding of the impact of human activity on the environment.

The interaction of science, technology, and society is the component of the science curriculum in which most environmental teaching can occur. Personal needs and societal needs objectives are closely related to environmental concerns. This guide recommends that these objectives be taught from third grade through high school, providing ample opportunity for environmental teaching. Developing appropriate values and attitudes toward the environment is a critical part of environmental education. A major outcome of teaching science, technology, and society is the ability to form values and make decisions.

Many subconcepts in the science knowledge component are essential to understanding the problems of the environment. Curriculum developers and teachers should be alert to situations whereby students will benefit from an environmental reference. At such times, students should have an opportunity to discuss, write, or act on the issues that are raised.

Computers in Science Education

As in all areas of the school program, science education can be enhanced by appropriate use of computers in both classroom management and instruction. Budgeting, maintaining supplies, word processing, record keeping, and a variety of other chores are made easier by using computers. Evaluation tasks are particularly simplified by computerized test grading, item selection, and record keeping.

Computer-assisted instruction can have valuable applications in science education because of the problem-solving component. The use of simulations is useful in teaching the processes of data analysis and explanation, and to a lesser extent, the processes of questioning and collecting data. The most effective computer usage in science education, although limited in possible applications, is to use computers directly in an interactive system for data gathering and analysis.

Computer-assisted learning provides an opportunity to use computer programs as effective instructional tools in the same way other media are used. The computer can be an instructional tool for drill and practice, inquiry, problem solving, tutoring for remediation, initial teaching, enrichment, and learning reinforcement. Well developed computer software can add dynamic and interactive versatility to the learning process. The following list defines some useful terms for exploring computer applications to teaching science.

Drill and Practice. Computer programs that review and reinforce concepts or skills already taught.

Tutorial. Computer programs that introduce or explain concepts and facts and may provide initial exposure to materials.

Simulation. Computer programs designed to model real-world environments with which students can investigate areas of science as well as other disciplines. Simulations allow students to make decisions and interact in situations that are often too complex, historical, expensive, dangerous, or distant to be brought into the classroom.

Discovery. Computer programs used to develop cognitive abilities in problem solving.

Instructional Gaming. Games designed to hold a user's attention and interest while teaching logical thinking. The games can make practice less tedious.

Word Processing. Use of the computer and specialty software which supports the writing, editing, formatting, and printing of reports and other written documents.

Data Bases. Use of the computer to collect, organize, retrieve, sort, display, and print data of all kinds.

Spreadsheets. Use of the computer and specialized software to simulate a business or scientific worksheet. Data entered into "cells" in the electronic worksheet can be calculated automatically by the spreadsheet program.

Telecommunications. Use of the computer and communications software to input, transmit, sort, receive, and display information from various sources.

There is good reason to implement computers in the science classroom, but there is also reason to use care not to extend computer usage beyond the tasks they do best. Direct experience with natural phenomena is essential to an effective science program. Computers can be incorporated into providing that experience, but they cannot supplant direct experiences.

Careers in Science and Technology

The national rationale for science education is primarily based on two goals: to develop a scientifically literate citizenry and to produce scientific and technological competence in individuals who will fill the jobs and do the necessary research and development for maintaining the position of the United States in a competitive world. Most of what is presented in this guide is directed at scientific and technological literacy. Yet the second goal of producing future scientists and technologists cannot be ignored.

A great many industrial applications of science and technology exist that require informed and capable individuals to fill necessary jobs. Although technology has often reduced the number of jobs needed to produce given products, jobs that remain or are newly created require greater problem-solving skills and science knowledge than ever before. In many cases the K-12 science curriculum must provide the science education individuals need to enter that job market. Therefore, it is obvious that the application of science learning to careers must be kept in mind while planning the science program.

Some students will choose to specialize in science and technology, of course. These students should be given every possible chance to become aware of the nature of professional opportunities in science and technology. There is a continuing need for engineers and technicians in the electronics, aerospace, bio-technology, medical, and other fields. In addition, there is a need for skilled scientists to be involved in basic research and development.

The need also exists for well educated, competent science teachers at all educational levels, including higher education. The growing shortage of certified secondary school science teachers—especially physical science teachers—is likely to continue for many years. Elementary teachers with strong science backgrounds have generally been scarce.

Careers in science and technology will bring many advantages to those who select them. Curriculum planners should make special efforts to assure that students are not only aware of science and technology career opportunities, but also that students who want to pursue such careers have the science education that will make it possible to do so.

Equity in Science Education

The state and the nation recognize the differences in the experiences of women and of men, of all races, colors, and ethnic groups, and of people of various physical and mental abilities. These factors often result in the sorting, grouping, and tracking of minority, female, and disabled students into stereotyped patterns that prevent them from exploring all options and opportunities according to their individual talents and interests. The cost of bias to academic achievement, psychological, and physical development, careers, and personal relationships is significant. Students should have the opportunity to grow, develop, and attain identity.

In science teaching, care must be taken to avoid sexual discrimination because of the traditional view that science, as well as applied mathematics, is more appropriate for males than for females. This view is not correct and should be challenged in every way. Young women should be encouraged to study science and to pursue careers in science and technology.

The science curriculum should be closely examined for sources of bias. These sources can be in blatant references in printed resources or they can be subtle references in the behavior of teachers. Regardless, they should be completely eliminated. To help in this process, curriculum planners and teachers should be alerted to six recognized forms of bias.

Invisibility: underrepresentation of certain groups, which leads to the implication that these groups are of less value and significance

Stereotyping: assigning only traditional and rigid roles or attributes to a group, thus limiting the abilities and potential of that group; denying students knowledge of the diversity, complexity, and variations of any group of individuals

Imbalance/selectivity: presenting only one interpretation of an issue, situation, or group; distorting reality and ignoring complex and differing viewpoints through selective presentation of materials

Unreality: presenting an unrealistic portrayal of history and contemporary life experience

Fragmentation/isolation: separating issues related to minorities and women from the main body of the text

Linguistic bias: excluding the role and importance of females by constant use of the generic "he" and sex-biased words

The K–2 Science Curriculum

8

K–2 Overview

Curriculum Development in Grades K–2

[illegible] K–2

Science [illegible] K–2

N[illegible] K–2

Science, Technology [illegible] K–2

[illegible] K–2

K-2 Overview

The skills of reading, writing, and arithmetic can be taught in a good K-2 science program.

Science at the kindergarten-2nd grade level is an integral part of the school program. It should be taught every day. Science should be used to integrate, reinforce, and enhance the other basic curricular areas to make learning more meaningful for children. Science teaching is important in the total elementary school curriculum because it supports achieving the goals of the entire school experience, particularly in basic skills development. The skills of reading, writing, and arithmetic can be taught in a good K-2 science program. Children have a high interest in science and like to read science-related books. Also, a direct science experience motivates students to read about it; a hands-on, problem-solving approach to science at the K-2 level can be expected to increase students' reading motivation.

A K-2 science program should emphasize applications to the students' world . . . .

The K-2 science program should reflect the developmental level of the children. Early science experience will help K-2 children develop the ability to draw simple conclusions and apply what they learn. Science begins at the K-2 level not only for the value it has for children's lives at the time, but also for the future, building the foundation which will support scientific literacy. A K-2 science program should emphasize applications to the students' world; the experiences and interests of children's day-to-day lives are the keys to a good science program. When developing the science program, teachers can consider the following questions. A science program developed with these considerations will prepare students to recognize individual and societal issues related to science and technology.

- What experiences do children have?
- What affects the lives of children?
- What surrounds children in their home, community, school?
- What do children talk about?

During K-2, the heaviest emphasis is placed on the problem-solving component . . . .

The distribution of time to be spent on each of the four science components changes as the child progresses through school. During K-2, the heaviest emphasis is placed on the problem-solving component, with less time spent on knowledge, the nature of science, and the interaction of science, technology, and society. However, these components are not taught separately, and time allocations are only guidelines for making curricular decisions. Science becomes an excellent vehicle for teaching beginning problem-solving skills while doing activities that students like and relate to their lives. Most children in grades K-2 are at a preoperational (sensory-motor) level of problem-solving skills. The objectives indicated for K-2 are directed to this functional level. The activities suggested will provide appropriate experiences to support these objectives.

The science curriculum must provide procedures for student evaluation that measure the student's progress toward the goals of the program. Care should be taken to evaluate more than simple recall and memorization of science knowledge. At the K-2 level, science knowledge is not an end in itself, but a vehicle to teach problem-solving and process skills. The K-2 years are the beginning of an experience that will lead to scientific literacy. Success at this level is indicated by measurable development of early problem-solving skills.

Curriculum Development in Grades K-2

Five options for developing a K-12 science curriculum are presented in section 4 of this guide. In addition, section 5 contains a procedure for curriculum development and worksheets to assist in that process. These sections are necessary preliminaries to developing a K-2 science curriculum.

After choosing a curriculum development option, curriculum planners should include the following considerations in the development process.

- The K-2 science curriculum should be an integral part of the district K-12 science curriculum.
- Children's developmental level and interests should guide curriculum development. The following Overview table can assist teachers in tailoring activities to children's problem-solving skills.
- The K-2 curriculum now should reflect the time allocations for the four components of science education (see table 9, p. 28). Note the suggestion that three of the components receive only 40 percent of science instructional time while the problem-solving component is allocated 60 percent of teaching time.
- Teaching science objectives should be integrated with other subject areas such as mathematics, language arts, social studies, and reading.
- Greatest emphasis in grades K-2 should be placed on developing problem-solving skills and not on the teaching of specific facts or concepts.
- Of the 22 major objectives of a K-12 science curriculum, only four are given high emphasis in grades K-2. However, the remaining 18 objectives cannot be ignored in the curriculum.
- Teacher demonstrations should be used in the course of study, but planned so they involve students. Students should not be limited to being passive onlookers.
- Activities should be included that require children to use all of their senses.
- Science need not be taught only in the classroom. Field trips—even a walk around the school—provide sensory experiences and enhance vocabulary development.
- Observing activities should be presented in a manner that helps children develop a vocabulary enabling them to express their observations.
- Opportunities should be included for students to read, write, and talk about the science experiences they have had.
- Outside resources should be used to gather ideas for classroom activities. Resources include science teachers in the district and publications, such as *Science and Children* and *Ranger Rick*.
- No curriculum is perfect. Curriculum planners should not strive for perfection nor expect it. However, the science curriculum should be continually revised and improved.

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Emphasis on Objectives

Recommended Time Allocation:
100 minutes per week

Total Relative Emphasis on Components

Problem Solving 60%
Science Knowledge 20%
Nature of Science 10%
Science, Technology and Society 10%

Component	High Emphasis	Medium Emphasis	Low Emphasis
1.0 Problem Solving	1.1 Ask questions 1.2 Collect data	1.3 Analyze data	1.4 Explain
2.0 Science Knowledge	2.1 Diversity 2.2 Change	2.3 Continuity	2.4 Interaction 2.5 Organization 2.6 Limitation
3.0 Nature of Science		3.5 Variety of methods	3.1 Evolution of science 3.2 Milestones 3.3 Assumptions 3.4 Accepted rules 3.6 Science/technology 3.7 Creative enterprise
4.0 Science, Technology, and Society		4.5 Personal needs	4.1 Attitudes 4.2 Economics 4.3 Politics 4.4 Societal needs

Developmental Problem-Solving Skills

Basic activities should involve students in

- making observations of the subjects around them (How many? What colors? What structure?)
- comparing physical properties (How are things alike? How are things different?)
- making direct measurements (How long? How tall? How heavy?)
- talking about their observations

. . . AND ALSO . . .

provide exposure to basic 3-6 activities

- classifying and ordering items using one variable (largest to smallest, shades of color)
- using observations to draw simple conclusions
- predicting possible results based on past experiences
- describing the thought processes used to reach a conclusion
- using trial and error to solve problems
- comparing the past with the present

BE AWARE students of this age have difficulty

- *accepting a point of view other than their own*
- *thinking in the past tense*
- *thinking in the future tense*
- *comparing objects by two or more characteristics at the same time (color and length, width and length, texture and color)*
- *understanding a logical sequence of thought (A leads to B, B leads to C, then A leads to C)*
- *learning about objects and their properties only by reading about them and not physically experiencing them*
- *dealing with abstract ideas and thought patterns (energy, tomorrow, evolution, atoms)*

Evaluation

Can students

- ask answerable questions about discrepant events?
- seek meaningful information?
- describe observations?
- compare quantities such as length, capacity, or weight?
- describe objects and events in terms of diversity and change?

Does the program

- meet minimum time allocations?
- match the characteristics of K-2 students?
- have the appropriate balance among the four components of science education?
- motivate students to learn science?
- provide a foundation for continuing with the 3-6 science curriculum?

Problem Solving/K-2

The formal teaching of problem-solving skills begins with an early emphasis in the primary grades. At the K-2 level, the students' intellectual ability limits the activities that can be undertaken. Repetitive strategies to develop skills are appropriate. Teachers' patience in developing fundamental skills at this level will lead to students displaying laboratory competence later.

The capacity to solve problems, both logically and creatively, is needed in all aspects of student and adult life. Such problem solving is seldom a single, linear process, yet the general procedure is a sequence of four groups of action: questioning, collecting data, analyzing data, and using the results to explain. At all levels, problem solving is given a major part of the allocated instructional time for science. At the K-2 level, it is recommended that 60 percent of instructional time be devoted to this component.

The four objectives for problem solving come directly from the four action groups. (See the 22 objectives for science education in section 3.) The following chart shows the related specific actions or processes with those most appropriate for K-2 science education in bold face capital letters. These are the source of subobjectives for curriculum development for problem solving at this grade level.

Problem solving is seldom a single, linear process . . . .

■ Grades K-2

Problem-Solving Action Groups

Questioning ↔	Collecting Data ↔	Analyzing Data ↔	Explaining
Noting patterns	**Observing**	Predicting	Describing
Noting discrepant events	**Measuring and quantifying**	Inferring	Defining
Seeking information	Identifying significance	Graphing	Interpreting
Formulating questions	Selecting variables	**Tabulating**	Developing mental models
Generating hypotheses	Estimating	Using numbers	Developing physical models
		Correlating	Communicating
		Classifying	

The specific actions in **boldface** type are to be emphasized at the K-2 level.

In the following table, the objectives for problem solving are given with examples of subobjectives and related activities. For problem solving, the subobjectives (specific actions) are reasonably complete, but others can be added. Only the high and medium emphasis objectives are included in the examples. These are only examples; other subobjectives can, and should, be developed. Many variations of the activities as well as absolutely different activities will be needed for complete treatment of the problem-solving component in the K-2 science curriculum.

1.0 Problem Solving/K-2

High Emphasis

1.1 Objective: Ask questions. The student shall ask answerable questions about nature.

Example Subobjectives		Example Activities	
1.11	Noting patterns. The student shall see relationships among objects and events.	1.111	Note similarities in a set of objects (e.g., all dogs have fur, all fish are in water, all rocks are hard).
		1.112	Note similarities in events (e.g., each day the sun rises and sets, thrown objects always fall to the ground.
1.12	Noting discrepant events. The student shall note exceptions to patterns.	1.121	Note unusual objects among groups of similar objects (i.e., a very dense block of wood sinks in water, some plants keep their leaves in winter).
1.13	Seeking information. The student shall use a variety of resources in seeking information about objects and events.	1.131	Use pictures and books to verify personal experiences.
		1.132	Manipulate objects to observe characteristics.
		1.133	Discuss objects and events with other students and teachers and compare responses.

1.2 Objective: Collect data. The student shall collect pertinent data from nature.

1.21	Observing. The student shall make accurate observations of objects and events using the senses or using instruments to aid the senses.	1.211	Distinguish differences in physical properties of objects by direct observation.
		1.212	Manipulate or change an object in order to expose its properties for observation.
		1.213	Use instruments to aid the senses in making observations.
		1.214	Make observations without drawing conclusions.
1.22	Measuring and quantifying. The student shall order by magnitude of measurable characteristics.	1.221	Order or group objects by inspection in terms of common measurable properties such as length, capacity, weight.
		1.222	Order or group objects by comparing to an arbitrary measuring device (e.g., comparing lengths to a stick of any given length).
		1.223	Measure gross lengths using a standard ruler.

Medium Emphasis

1.3 Objective: Analyze data. The student shall analyze data.

1.31	Predicting. The student shall use observations already made to predict new observations.	1.311	Use the observed taste of three pieces of apple to predict the taste of a fourth piece.
		1.312	From a list of statements choose those that can be used to make predictions (e.g., the sun rises in the east).
1.32	Classifying. The student shall use characteristics of objects to group them.	1.321	Group objects by a variety of characteristics (e.g., color, shape, size).

Science Knowledge/K-2

At the K-2 level, understanding science knowledge is secondary to problem solving. This component, although important, should only receive approximately 20 percent of the time allocated for science teaching at this level.

Of the six objectives (conceptual schemes) that make up the science knowledge component, the objectives identified as diversity and change have the greatest meaning for K-2 children. These concepts are demonstrated through many concrete examples that can be investigated in the classroom. Moreover, investigation of diversity and change among objects and events is easily integrated with early problem-solving activities. Therefore, diversity and change are the high emphasis objectives at the K-2 level. The high emphasis objectives for science knowledge should be considered with respect to all six of the objectives.

. . . diversity and change have the greatest meaning for K-2 children.

■ Grades K-2

Science Knowledge

Diversity. Natural phenomena display a wide variety of similarities and differences.

Change. The natural environment is constantly undergoing change.

Continuity. There is constancy in cause-and-effect relationships which makes change explainable.

Interaction. The interactions of matter and energy determine the nature of the environment.

Organization. Related systems within systems comprise the universe.

Limitation. Natural phenomena are limited by the fundamental nature of matter and energy.

. . . select criteria for science knowledge based on the nature of the learners rather than the organization of knowledge.

Curriculum planning at this level should be as flexible as possible in order to find the best knowledge context for appropriate student activity. Memorization of facts or information should not be stressed. Teaching of the knowledge component at this level is primarily directed at building the foundation for broad generalized understanding of the science knowledge objectives. Because of the breadth of science knowledge, it is possible to find an almost unlimited number of subobjectives that lead to specific classroom activities for each of the six science knowledge objectives. It is important to select criteria for science knowledge based on the nature of the learners rather than the organization of knowledge. No identifiable content, particularly at the K-2 level, must be taught regardless of existing textbooks or tradition. Curriculum planners should keep this fact in mind.

The following table gives the high and medium emphasis science knowledge objectives along with examples of subobjectives and related activities. These examples should be expanded to develop a complete curriculum for teaching the science knowledge component at the K-2 level. Note that the examples of subobjectives are grouped as biological, physical, and earth science examples. This is done only to organize ideas and does not mean that these subjects must be taught separately.

2.0 Science Knowledge/K-2

High Emphasis

2.1 Objective: Diversity. The student shall understand that natural phenomena display a wide variety of similarities and differences.

Example Subobjectives	Example Activities
Biological Science Examples	
2.11 Organisms can be grouped by specific structures.	2.111 Group students by sex, hair color, eye color, size of hands or feet.
	2.112 Distinguish between types of plants by comparing size, shape, kinds of leaves.
	2.113 Collect a variety of seeds and group them according to similarities and differences.
2.12 Plants and animals are different in different environments.	2.121 Visit habitats and describe the organisms found in each.
Physical Science Examples	
2.13 Objects have properties that can be detected with the senses.	2.131 Use the sense of touch to describe objects as rough/smooth, hard/soft, hot/cold.
	2.132 Use taste to identify foods as sour, sweet, salty, bitter.
	2.133 Compare sounds by quality, pitch, loudness.
2.14 Materials can be grouped according to their properties.	2.141 Group materials according to whether or not they float, sink, or dissolve in water.
	2.142 Observe the properties of materials that are gases, liquids, and solids.
2.15 Objects can be described by their quantitative (measurable) properties.	2.151 Compare objects by length, capacity, weight (heft).
Earth Science Example	
2.16 There are many types of rocks.	2.161 Collect rocks and group them by their texture, weight (density), and color.

2.2 Objective: Change. The student shall understand that our environment is constantly undergoing change.

Example Subobjectives	Example Activities
Biological Science Examples	
2.21 The appearance of living things varies with the seasons.	2.211 List plants and animals that appear different in different seasons. Describe the differences.
	2.221 Use infant pictures of students to observe ways they have changed since the pictures were taken.
2.22 Living things grow, age, and change in form and activity.	2.222 Observe changes in plants and small animals (insects) in the classroom. Describe the changes.
Physical Science Examples	
2.23 The direction or speed of moving objects will change when force is applied.	2.223 Compare members of students' families to describe differences that result from growing and aging.
	2.231 Explore ways to change the direction of a rolling ball.
	2.232 Blow through soda straws to move ping-pong balls, pieces of tissue paper.

2.2 Objective: Change (continued)

Example Subobjectives		Example Activities	
2.24	As time passes, cold or hot objects change in temperature.	**2.241**	Observe an ice cube melting. Feel the ice and then feel the water after the ice melts.
		2.242	Observe the change in a thermometer after a cup of cold water is placed for a while in sunlight.
2.25	Throughout each day, the apparent position of the sun changes.	**2.251**	Push sticks into the ground through pieces of paper. Mark the position of the shadow at different times on a sunny day. Describe what happened.
2.26	Rocks change over time by weathering.	**2.261**	Observe signs of weathering on an old brick building.
		2.262	Compare hard rocks (granite) and soft rocks (sandstone) as they are rubbed, scratched, or dropped.

Medium Emphasis

2.3 Objective: Continuity. The student shall understand that there is constancy in cause-and-effect relationships which makes change explainable.

	Biological Science Example		
2.31	Living things reproduce their own kind.	**2.311**	Raise plants, animals (e.g., fish, guppies, or mollies) in the classroom. Compare generations.
	Physical Science Example		
2.32	Matter can be changed in position, motion, shape, and other conditions and still retain its identifying characteristics.	**2.321**	Crumple, tear, throw pieces of paper. Note that after the changes the characteristics of the material are still those of paper.
		2.322	Freeze water, then melt the ice. Water remains.
	Earth Science Example		
2.33	Fossils are evidence that life processes have continued on earth for a very long time.	**2.331**	Examine fossils in rocks and compare to similar existing life forms. Compare similarities and differences.

Nature of Science/K-2

Each of the four components of science education must receive appropriate emphasis at all levels. Even though the nature of science is allocated only 10 percent of the total time for teaching science at the K-2 level, it is very important that the most concrete applications of this component be part of the science curriculum.

While science is primarily practiced by specialists, everyone, including young children, uses a variety of science processes to investigate and interpret events in the environment. K-2 students should have a chance to relate their activities to the real nature of science. Since the nature of science is mostly abstract, care must be taken to chose subobjectives and activities in this component related to concrete reasoning.

K-2 students should have a chance to relate their activities to the real nature of science.

■ Grades K-2

Nature of Science

- *History of Science*

  Evolution of Science. The knowledge and processes of science have evolved over a long period of time.
  Milestones. Science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

- *Philosophy of Science*

  Assumptions. Science is based upon assumptions about nature.
  Accepted Rules. Scientists operate within a generally accepted set of rules.

- *Actions and Interactions of Scientists*

  Variety of Methods. Scientists use a variety of methods to solve problems.
  Science/Technology. Science and technology are interdependent activities.
  Creative Enterprise. Science is a creative enterprise.

Notice that none of the objectives for the nature of science receive high emphasis. Only one objective (3.5 Variety of Methods) receives medium emphasis. The others have low emphasis. Working with these components at a low level of emphasis is a challenge. Activities should be integrated with other components or even with other subject areas in order to develop early awareness that will lead to a thorough understanding of the nature of science. For K-2 treatment of the nature of science, examples are given for the one medium emphasis objective and the two low emphasis objectives that have the best application to this level.

3.0 Nature of Science/K-2

Medium Emphasis

3.5 Objective: Variety of methods. The student shall understand that scientists use a variety of methods to solve problems.

Example Subobjectives	Example Activities
3.51 Scientists always seek better ways to make observations.	3.511 Find pictures of a variety of scientists making observations. Discuss the methods used.
3.52 There are many kinds of scientists who work in different ways.	3.521 Show pictures of nontypical scientists (foresters, oceanographers, etc.) Discuss the way they dress, their equipment.
3.53 Scientists have one thing in common—they all seek new knowledge by solving problems.	3.531 Show pictures of scientists doing research. Discuss what is the same about all of them.

Low Emphasis

3.1 Objective: Evolution of science. The student shall understand that science has evolved over a long period of time.

3.11 Scientists today use very different methods from those of scientists one hundred years ago.	3.111 Show pictures of scientists and laboratories then and now. Examine old and new equipment if available (or use pictures). Discuss changes.

3.1 Objective: Milestones. The student shall understand that science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

3.21 Major science theories can be used to explain many observed events.	3.211 Demonstrate a variety of falling objects to develop the idea of gravity. Ask for observations that can be explained by using that idea.

Science, Technology, and Society/K-2

Developing an understanding and appreciation for the interactions of science, technology, and society is essential to achieving scientific literacy. The science curriculum must be structured to bring gradual awareness of this interaction to children, enabling them to react intelligently to the issues that are raised in a society highly dependent on scientific-technological advances.

Students at the K-2 level should spend 10 percent of their science class time with the fourth component of science education. Because of the characteristics of these children, none of the five objectives for the component should be given high emphasis. Only the personal needs objective should receive medium emphasis. However, as with the nature of science, this lower emphasis does not mean that the interaction component can be ignored. This is the level where awareness begins, and, as with the other components, the more instruction relates to the personal experience of students, the better their achievement will be. K-2 students can become aware of the way science and technology affect the way people live, work, and play. They cannot become involved in the abstractions of economics and government

K-2 students can become aware of the way science and technology affect the way people live, work, and play.

■ Grades K-2

Science, Technology, and Society

Attitudes and Beliefs. Progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

Economics. Science and technology influence economic growth which, in turn, affects the progress of science and technology.

Politics. Science and technology influence political processes which, in turn, affect the progress of science and technology.

Societal Needs. Developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Personal Needs. Science and technology can affect individual lifestyles and the individual, in turn, responds to affect science and technology.

While developing the curriculum related to this component, all five of the interactions should be kept in mind even though four of them will receive low emphasis.

Before trying to develop subobjectives and activities for this component, teachers need to review the learning characteristics of K-2 students. Students at this level can receive information and sometimes respond to it; they will not be able to develop or use values related to issues that may be raised.

4.0 Science, Technology, and Society/K-2

Medium Emphasis

4.5 Objective: Personal needs. The student shall understand that science and technology can affect life styles and that the individual, in turn, responds to affect science and technology.

Example Subobjectives		Example Activities	
4.51	Developments in science and technology can improve or change the food we eat.	4.511	Sample a variety of crackers and describe their tastes. Ask parents which kinds of crackers they had when they were young. Discuss reasons for the difference.
		4.512	Collect advertisements of or labels from new or improved breakfast cereals.
4.52	Developments in science and technology can help people care for themselves.	4.521	Find evidence of changes in toothpaste or soup.
		4.522	Study a picture of children many years ago. How are present conditions better for today's children?
4.53	The use of new developments in science and technology affect the air we use.	4.531	List products (deodorants, hairspray, furniture polish) and wastes (smoke, exhaust fumes) that go into the air.
		4.532	Describe odors that can be detected inside or outside of the school.

Low Emphasis

4.4 Objective: Societal needs. The student shall understand that developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

4.4	A continuous supply of energy is necessary for our society to function.	4.411	Discuss what might happen if the gas or oil for our furnaces ran out in the winter. What alternatives are there?
		4.412	Collect pictures of a variety of common products. Sort the pictures in two piles according to those that need a lot of energy to produce and those that do not. (Look for awareness, not accuracy.)

Characteristics of Students and Science Program

Students

Students at this age level are continually discovering more of their world, and are expanding their language and other communication skills. Science provides an opportunity to focus on real objects and events. Science provides the teacher with excellent opportunities to record growth in reasoning and problem-solving skills.

Program

- Problem-solving objectives, recommended for high emphasis at the K-2 grade level—include asking questions and collecting data, with medium emphasis on analyzing data. Abstract ideas and technical terms are inappropriate at this level. Asking questions and collecting information can help students of this age learn about their world. This forms a firm basis for the study of science.
- Science knowledge focuses on diversity and change.
- The nature of science is primarily limited to concern for the variety of methods used in science.
- Science, technology, and society does not receive high emphasis at this level, but teaching the relationship of science to personal needs is very appropriate and can be an effective means of introducing this component.

Evaluation Tips

Science evaluation at the K-2 level should make use of students' verbal ability in describing objects and events. Most evaluation will take place through teacher observation and the child's early efforts to use symbols, pictures, and words. Just as in other areas of the primary school curriculum, the teacher can judge performance through observing verbal reactions, play activities, and the expanding use of symbols.

Emphasis for evaluation should be on early problem-solving skills.

The major emphasis for evaluation at this level should be on early problem-solving skills. Teachers can observe the students' reaction to discrepant events, and their ability to respond with answerable questions and describe observations. Then teachers can take notes as data to be used both for individual progress evaluations and for evaluating the success of the curriculum. Teachers should always keep in mind the typical characteristics of students of this age when determining individual progress in problem-solving skills.

Science knowledge objectives focus on diversity and change. Evaluation of these learning outcomes should focus on events within the child's own experience—e.g., the diversity of plants, animals, and people, as well as changes in seasons, weather, and personal growth. Observing students as they describe the changes that take place in a loaf of bread as it rises and is baked can provide significant information on their ability to apply the concept of change. Children can show evidence of understanding diversity and change through verbal descriptions of what is seen and comparisons with other objects and events.

The nature of science, though quite an abstract concept for these grade levels, can be introduced via the variety of methods used to "find out." Again, evaluation of this objective involves teacher observation. Exercises such as having children create pictures of how they would explore an event, plant, or animal can indicate understanding.

The interactions of science, technology, and society can be taught and evaluated in a manner appropriate to these grade levels, where science touches the child's personal needs. The use of controlled observations and an attitude of "let's find out" can lead to understanding the rationale for scientific experiments. This attitude of inquisitiveness can promote intellectual growth related to science, technology, and society issues.

The 3–6 Science Curriculum

9

3–6 Overview
Curriculum Development in Grades 3–6
Problem Solving/3–6
Science Knowledge/3–6
Nature of Science/3–6
Science, Technology, and Society/3–6
Evaluation/3–6

3-6 Overview

There is no real boundary between grade 2 and grade 3; curriculum planners should use care to establish continuity between the two grade-level groupings. However, as students approach grade 3 (age 8), their overall characteristics can be expected to change rapidly so that they are able to participate in activities with a higher level of intellectual development. It is important to keep the level of science activities sufficiently high to challenge students to reach the next level of problem-solving and intellectual skills.

The known characteristics of growing children have been used to determine the recommended time allocation for each of the four components and for the relative emphasis for specific objectives within components. Students in grades 3-6 will be able to extend their thoughts from the present to the past or future, from the actual to the potential. They can develop new understanding by reorganizing existing information. At this age students begin to reason inductively. These changes are important guides to extending the science curriculum to the intermediate grades.

Students in grades 3-6 will be able to extend their thoughts from the present to the past or future, from the actual to the potential.

At the 3-6 level, the study of science continues to give strong support to developing reading, writing, and mathematics skills. As in the K-2 level, more emphasis should be placed on the problem-solving component than on the other science components. But as the student nears the sixth grade, the teaching emphasis should shift toward that indicated as appropriate for middle/junior high school students. This shifting is particularly significant at this level, as the allocated time for teaching science rapidly increases from a recommended minimum of 150 minutes per week in grade 3 to 250 minutes per week in grade 6.

The school district and teacher will need to measure students' progress as they participate in science. Pre-testing and post-testing are recommended for determining achievement. Observations made during class periods will also be used to determine the ability of students to use science skills.

Curriculum Development in Grades 3-6

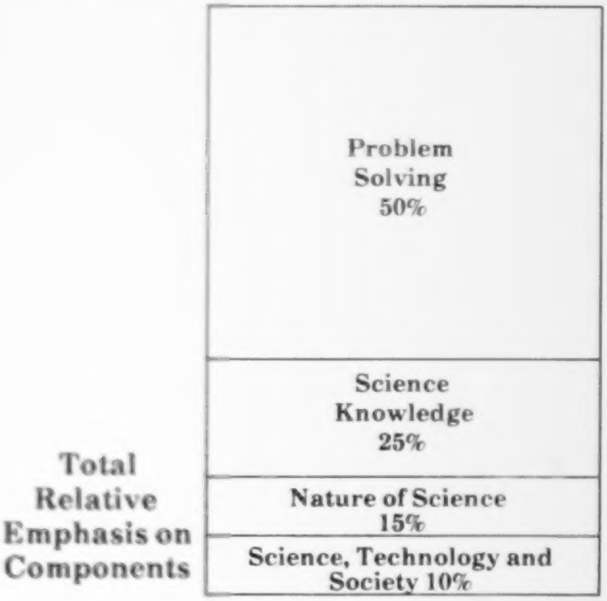
Five options for developing a K-12 science curriculum are presented in section 4 of this guide. In addition, section 5 contains a procedure for curriculum development and worksheets to assist in that process. These sections are necessary preliminaries to developing a 3-6 science curriculum.

After choosing a curriculum development option, curriculum planners should include the following considerations in the development process.

- The 3-6 science curriculum should be an integral part of the district K-12 science curriculum. It should be based upon the skills and knowledge developed in grades K-2 and form the basis for the science curriculum in the middle/junior high school grades.
- Children's developmental level and interests should guide curriculum development. Students in this age group have difficulty understanding the role of variables and controls in experiments and are not ready to design their own experiments.
- The 3-6 curriculum should reflect the time allocations for each of the four components of science education (see table 9, p. 28). Note the suggestion that 50 percent of science instructional time in grades 3-6 be allocated to developing problem-solving skills while the teaching of science facts and unifying principles is given only 25 percent of instructional time.
- Teaching of science objectives should be integrated with other subject areas such as mathematics, language arts, social studies, and reading.
- Of the 22 major objectives of a K-12 science curriculum, only six are given high emphasis in grades 3-6. However, nine other objectives receive medium emphasis and none can be completely ignored.
- Students should have a chance to learn from "hands-on" experiences before being assigned text or other reading assignments.
- Field trips should be used as a method of having students collect, organize, and analyze data outside of the classroom.
- Students should be involved in solving real problems. Such problems should be presented with a definite purpose, have directions to follow, and require the use of one or more manipulative skills. The problems chosen should have simple solutions.
- Activities should be included that require students to collect qualitative data (e.g., color, the warmest, the hardest) and others that require quantitative data (e.g., How much? How fast? How long?).
- Activities should be included that will require students to organize their data into charts, tables, and/or simple graphs.
- Outside resources should be used to gather ideas for classroom activities. Resources include science teachers in the district, a science specialist, and publications, such as *Science and Children* and *Science Activities*.
- No curriculum is perfect. Curriculum planners should not strive for perfection nor expect it. However, the science curriculum should be continually revised and improved.

Emphasis on Objectives

Recommended Time Allocation:
200 minutes per week



Component	High Emphasis	Medium Emphasis	Low Emphasis
1.0 Problem Solving	1.1 Ask questions 1.2 Collect data	1.3 Analyze data 1.4 Explain	
2.0 Science Knowledge	2.1 Diversity 2.2 Change	2.3 Continuity 2.5 Organization	2.4 Interaction 2.6 Limitation
3.0 Nature of Science	3.5 Variety of methods	3.1 Evolution of science 3.2 Milestones 3.6 Science/technology	3.3 Assumptions 3.4 Accepted rules 3.7 Creative enterprise
4.0 Science, Technology, and Society	4.5 Personal needs	4.1 Attitudes 4.4 Societal needs	4.2 Economics 4.3 Politics

Developmental Problem-Solving Skills

Basic activities should involve students in

- using their observations to draw simple conclusions
- classifying and ordering items using one variable (largest to smallest, shades of color
- using trial and error to solve problems
- predicting possible results based on past experiences
- describing the thought processes used to arrive at conclusions
- comparing the past with the present

. . . AND ALSO . . .

provide exposure to basic middle/jr. high activities

- predicting unknown data from data that is known (extrapolate)
- understanding a thought sequence based on simple logic (A leads to B, B leads to C, then A leads to C)
- dealing with simple abstract ideas
- visualizing simple models presented to them
- discovering cause-and-effect relationships
- intuitively understanding proportions

BE AWARE students of this age have difficulty

- *thinking abstractly*
- *formulating many alternative solutions to a problem*
- *making a formal hypothesis that includes a possible cause and predicts a possible outcome (if . . . then reasoning)*
- *approaching a problem through formal sequential reasoning (do A, then B, then C)*

Evaluation

Can students

- formulate questions that can be answered by investigation?
- use quantitative measures to collect data?
- tabulate and display data?
- use numbers to analyze data?
- describe observations and results of analysis in written form?
- use simple instruments to collect data?
- use the concepts of diversity, change, continuity, and organization to describe their environment?
- exhibit an early understanding of the history of science and the process used by scientists?
- describe the way science and technology affects their lives and the lives of others in their community?

Does the program

- provide for the minimum allocation of time for teaching science?
- grow in sophistication and challenge as the students develop?
- continue emphasizing problem solving while phasing in the other components?
- give students an opportunity to enjoy doing science activities?
- prepare students to advance into the middle/junior high school science curriculum?
- include a systematic review of the effectiveness of units, modules, or specific activities?

Problem Solving/3-6

Students should begin to develop confidence and independence in the laboratory.

Developing problem-solving skills continues to be the major emphasis for the science curriculum at this level. Even though the recommended time allocation is reduced from 60 percent at the K-2 level to 50 percent at the 3-6 level, the actual time devoted to problem solving will increase as the total science teaching time increases (250 minutes per week minimum in grade 6). As students proceed from grade 3 to grade 6, they should begin to develop confidence and independence in the laboratory. The tasks they will undertake will increase in difficulty, and they will learn to depend on their observed data rather than appeal to the teacher or written resources for confirmation.

The total process of investigation can be introduced in its simplest form at the 3-6 level. The students can discover direct cause-and-effect relationships. The emphasis on the processes of analysis can be somewhat increased, and the processes of explanation can be introduced. On the following chart the specific actions or processes that are most appropriate for this level are presented in bold face. These processes are the source of subobjectives for 3-6 curriculum planning for the problem-solving component.

■ Grades 3-6

Problem-Solving Action Groups

Questioning ↔	Collecting Data ↔	Analyzing Data ↔	Explaining
Noting patterns	**Observing**	**Predicting**	**Describing**
Noting discrepant events	**Measuring and quantifying**	**Inferring**	**Defining**
Seeking information	Identifying significance	Graphing	Interpreting
Formulating questions	Selecting variables	Tabulating	Developing mental models
Generating hypotheses	Estimating	Using numbers	Developing physical models
		Correlating	Communicating
		Classifying	

The actions in **boldface** type are to be emphasized in grades 3-6.

The following table indicates the objectives that should be given high and medium emphasis for the problem-solving component. The subobjectives indicated describe the four objectives quite completely. However, other subobjectives can be developed. The example activities are just that. Many additional activities will have to be devised for each grade level to give students ample opportunity to develop competence in problem solving.

1.0 Problem Solving/3-6

High Emphasis

1.1 Objective: Ask questions. The student shall ask answerable questions about nature.

Example Subobjectives	Example Activities
1.11 Noting patterns. The student shall see relationships among objects and events.	1.111 Look for repeated events – the seasons, calm before a storm, migration, phases of the moon, eclipses.
	1.112 Describe relationships among living things in an environment.
1.12 Noting discrepant events. The student shall note exceptions to patterns.	1.121 Look for individual plants or animals that have characteristics different from most of their kind (four–leafed clover, unusual coloration, stunted growth). Discuss possible reason or differences.
	1.122 Observe that a helium–filled balloon in a car goes forward when the car speeds up. Why is this unusual?
1.13 Seeking information. The student shall use a variety of resources in seeking information about objects and events.	1.131 Study all the characteristics of a wilted plant before asking why it wilted.
	1.132 Locate a variety of sources of information that describe the way dew forms on grass.
1.14 Formulating questions. The student shall use initial information to ask questions that are structured so that they can be answered by investigation.	1.141 Use collected observations of butterflies to formulate questions about the food they eat (i.e., do butterflies eat leaves, other insects, pollen?).
	1.142 Practice asking questions that require only a yes or no answer.
	1.143 From a list of questions, pick those that could be answered by making observations from those that require theoretical answers.

1.2 Objective: Collect data. The student shall collect pertinent data from nature.

Example Subobjectives	Example Activities
1.21 Observing. The student shall make accurate observations of objects and events using the senses or using instruments to aid the senses.	1.211 Describe complex objects by observing their essential characteristics (e.g., a flower, a clock, a typewriter).
	1.212 Use optical devices to improve visual observations.
	1.213 Verify observations of the characteristics of maple trees by examining several different trees.
	1.214 From a list of observations of a series of events that lead to a specific effect, separate observations that are related to the effect from those that are extraneous.
	1.215 Identify, from statements about an effect, those that are observations and those that are inferences.
1.22 Measuring and quantifying. The student shall use standard measuring devices to collect data.	1.221 Practice measuring length by comparison to a standard unit of length (e.g., centimeter, meter).
	1.222 Compare capacity of a pail to the standard liter.
	1.223 Use a Celsius thermometer to measure temperature.
	1.224 Use a simple balance to measure mass in grams and kilograms.
	1.225 Measure rates of change using the second, minute, or hour (e.g., movement of a shadow cast by a stick in sunlight, change in temperature during the morning).
	1.226 For a given observation, choose the most appropriate unit and measuring device.

1.0 Problem Solving/3-6 (continued)

Medium Emphasis

1.3 Objective: Analyze data. The student shall analyze data.

Example Subobjectives	Example Activities
1.31 Predicting. The student shall use observations and known information to predict events.	**1.311** Cover a burning candle with bottles of different sizes and note the time until the candle goes out. Predict the time for another bottle of still a different size.
	1.312 From a list of statements made by students about the future, separate those that are informed predictions from those that are guesses.
	1.313 Use weather observations to predict conditions the next day.
	1.321 Describe the difference between an observation and an inference.
1.32 Inferring. The student shall use observations to make inferences.	**1.322** Use a list of observations of a spider building a web to make an inference about the reason for the behavior, or the function of the web.
1.37 Classifying. The student shall use the characteristics of objects or events to group them by noting similarities.	**1.371** From an arbitrary set of objects describe the characteristics that are often repeated (color, shape, texture).
	1.372 Group a set of similar objects (buttons, marbles, blocks of wood) according to special characteristics. Regroup them using other characteristics.
	1.373 Describe or invent a system that could be used to group plants found in a lawn or garden.

1.4 Objective: Explain. The student shall use the results of analysis to explain natural phenomena.

1.41 Describing. The student shall use observed characteristics of objects or events to develop verbal and written descriptions of them.	**1.411** Use both qualitative and quantitative characteristics to describe a piece of sculpture, a plant, a rock.
	1.412 Use qualitative and quantitative observations to describe what happens when a rubber ball is dropped from a given height.
1.42 Defining. The student shall use the common characteristics of sets of objects or events to develop definitions that include the members of those sets.	**1.421** From observations of many kinds of dogs, develop a definition of "dog."
	1.422 Using a specific case of a ball rolling on a flat, level surface, develop a definition of the concept "speed."
	1.423 Describe the difference between operational and nonoperational definitions.

Students in grades 3-6 will spend approximately 25 percent of the instructional time in science systematically working to understand broad science concepts. However, this activity must be integrated with learning the other three science components. Although teacher-directed discussion is often appropriate, learning will be best accomplished through laboratory investigations and demonstrations. The students have concrete-operational thinking and problem-solving skills. They need direct experience with the phenomena being studied, cannot deal well with abstract ideas, and depend on observations to relate cause to effect. They can work with quantities that can be directly measured such as length, capacity, and time, but have trouble with derived quantities using two or more combined measurements such as density or pressure. In this age group, the children's ability to understand and assimilate concepts improves rapidly, but care must be taken to avoid exceeding their ability to reason.

Students need direct experience with the phenomena being studied.

■ Grades 3-6

Science Knowledge

Diversity. Natural phenomena display a wide variety of similarities and differences.

Change. The natural environment is constantly undergoing change.

Continuity. There is constancy in cause-and-effect relationships which makes change explainable.

Interaction. The interactions of matter and energy determine the nature of the environment.

Organization. Related systems within systems comprise the universe.

Limitation. Natural phenomena are limited by the fundamental nature of matter and energy.

The teaching of science knowledge should not be limited to teaching facts and principles. Facts are necessary, but they should be put to use in reasoning and problem solving. Teachers at this level should choose activities that go beyond simple repetition and recognition, and avoid the tendency to overburden students with too much knowledge content. The following guidelines are useful in developing science concept learning activities for grades 3-6. Curriculum developers and teachers need to

- select knowledge content that relates to the past experience of students;
- be aware of the students' level of intellectual development and select content and teaching strategies accordingly, while striving to accommodate individual differences;

- provide learning experiences that will help students move from their level of intellectual development to the next higher level.

The goal of scientific literacy should always be kept in mind while developing a science curriculum. In order to reach this goal, students need a broad understanding of science knowledge, along with confidence and interest in science that develops from success in the science classroom. Teaching science knowledge at the 3-6 level is better devoted to producing that success than to exposing students to excessive amounts of factual content that they may not retain or find useful.

. . . students need a broad understanding of science knowledge, along with confidence and interest in science that develops from success in the science classroom.

In grades 3-6, high emphasis continues to be placed on the concepts of diversity and change with continuity and organization receiving medium emphasis. The high and medium emphasis objectives should be considered in the context of all six objectives for the science knowledge component. As at other levels, only a few examples of subobjectives have been selected from the many that can be used. Curriculum developers should use their experience or other resources to identify specific subobjectives and activities. Examples are given only for the high and medium emphasis objectives; this does not imply that application of the low emphasis objectives should be ignored.

2.0 Science Knowledge/3-6

High Emphasis

2.1 Objective: Diversity. The student shall understand that natural phenomena display a wide variety of similarities and differences.

Example Subobjectives	Example Activities
Biological Science Examples	
2.11 Organisms can be grouped by specific structures or by the habitats in which they live.	2.111 Visit different habitats and identify and describe the organisms found in each.
	2.112 Observe the differences and similarities found in common plants and animals.
	2.113 Group plants found in a yard or field according to common characteristics
2.12 Much of the diversity which exists in the living world is because of adaptations to the environment.	2.121 Study the specialization of bird beaks and bird feet.
	2.122 Examine those specialized structures that allow insects to survive in their habitats.
	2.123 Compare the habits and behaviors of animals to demonstrate adaptation to the environment.
2.13 Organisms can be grouped according to man-made criteria and placed in predetermined categories. These criteria are subject to change.	2.131 Watch moths and butterflies; observe their attributes and determine their classification.
	2.132 Make collections of leaves, insects, or seeds, and name the organisms using classification keys.
	2.133 Have students collect organisms and have them develop their own schemes for classification.
Physical Science Examples	
2.14 Matter is described in terms of properties which can be detected with the senses.	2.141 Compare properties of water, ice, air to determine similarities and differences of matter.
	2.142 Compare oil, water, and alcohol by observing which "floats" on the other.
2.15 When energy is added to or taken from matter, some of the properties are changed.	2.151 Allow ice to melt, break a nut shell with a hammer, burn wood splints, file wood splints into sawdust. Ask in each case what was added to change the original form of the matter.
	2.152 Freeze water in a sealed plastic container. Explain what must have caused the change.
	2.153 Observe expansion of air molecules as air is heated, and contraction as air is cooled by using a pyrex flask with a balloon over the neck.
2.16 Matter may be classified according to exhibited properties under a given set of conditions.	2.161 Observe examples of "thick and thin" liquids (slow-pouring and fast-pouring). Group liquids according to observed properties.
	2.162 Apply heat (fire) to wood, styrofoam, glass, paraffin, steel, and plastic. Classify according to observed properties.
2.17 Most matter can be classified as solid, liquid, or gas.	2.171 Observe condensation on a cold surface.
	2.172 Observe evaporation off of a blackboard.
	2.173 Have students classify solids, liquids, and gases from a given list of mixed examples. (Introduce examples such as soft butter or gelatin as questionable substances.)
2.18 Energy can be classified as kinetic or potential.	2.181 Use a pendulum to illustrate both forms of energy—kinetic/moving and potential/position.
	2.182 Show how kinetic energy is continuously being transformed into potential energy and vice versa as a pendulum swings.
	2.183 Identify examples of objects in the classroom that have potential energy. Describe how that energy could be changed to kinetic.

2.0 Science Knowledge/3-6 (continued)

2.1 Objective: Diversity (continued)

Example Subobjectives		Example Activities	
Earth Science Examples			
2.19	There are many different kinds of rocks.	2.191	Collect rocks of different types.
		2.192	Group rocks by properties: heavy/light, rough/ smooth, color, layered/aggregate, hardened liquid.
		2.193	Compare texture differences of sandstone, granite, lava rock, pumice, etc.
2.1(10)	Rocks can form in different ways.	2.1(10)1	Model sedimentary rock by allowing mud, sand, and gravel to settle out of moving water.
		2.1(10)2	Model igneous rock by freezing melted paraffin.
2.1(11)	Rocks break down to form different kinds of sediment.	2.1(11)1	Pulverize small rock fragments and compare.
		2.1(11)2	Shake rock fragments in water. Observe sediment. Compare the layering of fragments with rocks that have not been processed in water.
2.1(12)	The variety of rocks is the result of differences in mineral composition and history of formation.	2.1(12)1	Examine sedimentary, igneous, and metamorphic rocks. Record differences and similarities. Describe ways the rocks could have been formed.

2.2 Objective: Change. The student shall understand that our environment is constantly undergoing change.

Biological Science Examples			
2.21	As living things grow and age, they change in form and activity.	2.211	Raise plants and animals and observe the changes in the organisms as they mature.
		2.212	Describe changes noted in friends and relatives in the past few years.
		2.213	Observe the metamorphosis of moths, butterflies, meal worms.
2.22	The fossil record indicates that there has been a change in the form and complexity of life over time.	2.221	Study fossils, or books about fossils, to examine evidence that change in life forms has occurred.
		2.231	Let a plant go dry, overwater another. Observe the effect of temperature change on plants.
2.23	Changes in specific environments can cause a change in the kinds of organisms that can live in the environment.	2.232	Study fossils in an area. Determine if the same plants or animals could live in the area now.
Physical Science Examples			
2.24	A moving object will change its speed or direction only when a force is applied.	2.241	Explore ways the direction of a ball rolling on a hard floor can be changed (blowing, deflecting, colliding, etc.). Decide what these effects have in common.
		2.242	Make a bicycle, wagon, car go faster (or slower). Determine the cause of these changes.
2.25	The temperature of matter changes when energy is exchanged between the matter and its environment.	2.251	Place a beaker of cold water in bright sunlight (or over a small flame or heating element). Record temperatures over time. Remove from heat source and continue recording temperatures.
		2.252	Place a hot brick in cold water. Observe changes.
2.26	When the forces applied to matter are changed, some of the properties of the matter may be changed.	2.261	Set a heavy weight (a can filled with sand) on top of an ice cube. Compare the melting of the stressed cube with one melting without stress.
Earth Science Examples			
2.27	Rate of weathering depends on the characteristics of the material being weathered and on the cause of weathering.	2.271	During the school year, expose to the outdoors a steel can, plastic bag, aluminum can, piece of cardboard, limestone rock, granite rock. Periodically record observations of any change.

2.2 Objective: Change (continued)

Example Subobjectives	Example Activities
	2.272 Drip water onto a pile of sand and a mound of clay to observe different rates of weathering. Drip water, then vinegar, on limestone.
2.28 Changes in the relative position of the earth and sun causes changes in the seasons and in the length of day and night.	**2.281** Make a model of the earth with a styrofoam ball with a dowel through it as an axis. With a single small light source on a table in a darkened room, investigate the effect of moving the ball around the light keeping the axis pointing in the same direction.
2.29 The changing phases of the moon depend on the relative position of the sun, moon, and earth.	**2.291** Use the same ball and dowel to demonstrate the phases of the moon to an observer in a fixed position.

Medium Emphasis

2.3 Objective: Continuity. The student shall understand that there is constancy in cause-and-effect relationships which makes change explainable.

Biological Science Examples	
2.31 Animals exhibit behaviors that are hereditary.	**2.311** Observe kittens washing their faces, young squirrels eating sunflower seeds, etc. Propose reasons for this behavior.
2.32 Plants reproduced by asexual methods have the same characteristics as the parent plants.	**2.321** Grow plants from cuttings, bulbs, tubers, etc. Compare them to the parent plants.
Physical Science Examples	
2.33 Matter can changed in position, motion, shape, and other conditions without changing its identity or quantity.	**2.331** Change a piece of clay by squeezing, bending, pulling. Compare its characteristics and weight before and after.
2.34 There are special properties of kinds of matter that are always the same.	**2.341** Make several determinations of the boiling temperature of water, the weight (mass) of a liter of water, etc.
Earth Science Examples	
2.35 Fossils found in rocks suggest that life processes have continued in the same way for a long time.	**2.351** Study fossils to find structures that are similar to those of existing plants and animals.
2.36 The length of day and night always varies in a predictable way.	**2.361** Find records of past years giving the time of the longest and shortest days of the year. Discover how the winter and summer solstice, fall and spring equinox are predicted.

2.4 Objective: Organization. The student shall understand that related systems within systems comprise the universe.

Biological Science Examples	
2.41 Living things exist within ecosystems in which each organism is adapted to its living and nonliving environment.	**2.411** Study bird structures (feet, wings, beaks) to show that they are adapted to their environment. Discuss what would happen if these structures were different. **2.412** Establish a balanced terrarium. Describe the role of each organism in maintaining the balance.
Physical Science Examples	
2.42 The properties of an object depend on the properties and function of its physical parts.	**2.421** Use a battery, a bulb, and some wire to make a system that will light the bulb. **2.422** Disassemble an old watch (radio, garbage disposal) and try to describe the function of each major part.
Earth Science Examples	
2.43 The earth, moon, and sun move together as a system.	**2.431** List the effects the earth, moon, and sun have on each other. Describe what would happen if any of the three were removed from the system.

Nature of Science/3-6

> *Children in grades 3-6 are able to consider events in the history of the development of science, and they can make comparisons between the past and the present.*

Somewhere near the third grade, children show a greater ability to reorganize concepts into new generalizations. They begin to use observations or new ideas to form conclusions. Although the abstract notions of the philosophy of science are beyond their understanding, they are able to consider events in the history of the development of science, and they can make comparisons between the past and the present. As the students progress to grade 6, their ability to consider the way scientists work increases, and the overall nature of science becomes more understandable.

It is recommended that the nature of science component receive approximately 15 percent of the time allocated for science instruction at this level. The objective of understanding the variety of methods scientists use should be the only objective receiving high emphasis. However, the history of science (evolution of science and milestones) and science/technology should receive medium emphasis. The introduction of these new objectives should be treated carefully to avoid the abstract or complicated science knowledge that is usually associated with the historical development of science and technology.

■ Grades 3-6

Nature of Science

- *History of Science*

  Evolution of Science. The knowledge and processes of science have evolved over a long period of time.
  Milestones. Science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

- *Philosophy of Science*

  Assumptions. Science is based upon assumptions about nature.
  Accepted Rules. Scientists operate within a generally accepted set of rules.

- *Actions and Interactions of Scientists*

  Variety of Methods. Scientists use a variety of methods to solve problems.
  Science/Technology. Science and technology are interdependent activities.
  Creative Enterprise. Science is a creative enterprise.

At this level, there are many classic demonstrations that can be used as examples of discrepant events that lead to problem-solving activities. Galileo's observations of falling objects and swinging pendulums are good examples. Above all, science should be made interesting; the memorization of details should not be overemphasized. Dates, names, and places should not take precedence over the context in which progress in science has occurred.

There are many classic demonstrations that can be used as examples of discrepant events that lead to problem-solving activities.

As with the other components, the following table gives examples of subobjectives and activities that could be used to teach toward the high and medium emphasis objectives. No examples are given for the low emphasis objectives, but they should still be included in teaching where they can be applied within the ability of students in this age group.

3.0 Nature of Science/3-6

High Emphasis

3.5 Objective: Variety of methods. The student shall understand that scientists use a variety of methods to solve problems.

Example Subobjectives	Example Activities
3.51 Science is applied to a variety of problems that require many approaches to finding solutions.	**3.511** Identify a list of scientific or technological problems that have been solved. Discuss the difference in materials and methods that might have been used.
	3.512 Discuss the difference between the work of a biologist and a chemist, a geologist and an astronomer.
	3.513 Find the meaning of the word "alchemist." Discuss the ways that alchemists tried to solve problems.
3.52 Science can be practiced by many kinds of people at different levels of complexity.	**3.521** Make a list of words (adjectives) that describe scientists. Decide which words could describe students practicing science in school; which words only apply to research scientists.
	3.522 Identify individuals students know (or know about) who might be called scientists. Compare the work of the individuals.
3.53 There is no single "scientific method" that is used by all scientists.	**3.531** Look for descriptions of a so-called scientific method and compare them. If possible, ask local scientists what methods scientists use.

Medium Emphasis

3.1 Objective: Evolution of science. The student shall understand that the knowledge and processes of science have evolved over a long period of time.

3.11 Early scientists had very little knowledge of the interaction of matter and energy.	**3.111** Discuss the early concept of four elements (earth, air, fire, and water) comprising the universe.
	3.112 List science facts that students commonly know (atoms, light as waves, kinetic and potential energy), and try to find out when these facts were first known and accepted.

3.2 Objective: Milestones. The student shall understand that science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

3.21 There have been many great scientists who are remembered primarily for the new solutions they developed for problems that others could not solve.	**3.211** Discuss the reasons why people like Newton, Curie, Copernicus, Einstein are so important in the history of science.

3.6 Objective: Science/technology. The student shall understand that science and technology are interdependent activities.

3.61 Both science and technology involve recognizing problems, using known information, and proposing solutions.	**3.611** Compare the work of known scientists to known technologists (i.e., compare a scientist studying the behavior of apes in Africa to the work of a technologist developing a metal alloy for lightweight space craft).
3.62 The knowledge produced by science is used by technologists to produce new products.	**3.621** Consider the knowledge that was put to use to produce electronic hand calculators.
3.63 The products of technology are used by scientists to produce new knowledge.	**3.631** Consider the special instruments that have been used to study human genetics.

By the time students reach the intermediate grades they have a developing awareness of the conditions around them that affect their lives. They are accustomed to using the various technological systems that are provided to them in their homes, school, and communities. They know how to interact with their environment and are beginning to want to control what happens to them. For this reason, the study of the interaction of science, technology, and society should place high emphasis on the personal-needs objective. As students progress, their concerns for other aspects of society will develop and the societal needs objective can be introduced. They will also begin to understand how attitudes and beliefs are affected by developments in science and technology and how societal needs and attitudes control future developments.

Children in grades 3-6 know how to interact with their environment and are beginning to want to control what happens to them.

■ Grades 3-6

Science, Technology, and Society

Attitudes and Beliefs. Progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

Economics. Science and technology influence economic growth which, in turn, affects the progress of science and technology.

Politics. Science and technology influence political processes which, in turn, affect the progress of science and technology.

Societal Needs. Developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Personal Needs. Science and technology can affect individual lifestyles and the individual, in turn, responds to affect science and technology.

Curriculum developers should approach only the broad aspects of this component at this level; there could be a tendency for teachers to provide excessive amounts of information to children without soliciting their responses. Activities should be designed that allow students to read, write, listen, and discuss simple issues that affect their lives. Students still need direct experience as the foundation for learning; they are egocentric and have difficulty with abstract thinking. Students have little success in assigning values to issues and they seldom are able to organize consistent systems of thought that can be transferred from one issue to another.

The allocation of time for the science, technology, and society component remains at a relatively low 10 percent, but careful attention to teaching and learning strategies can make student experiences related to studying science, technology, and society a very important part of science education in these grades.

In the following table, the examples of subobjectives and activities are directed at considering alternatives; this is somewhat different from the K-2 level where awareness was stressed.

4.0 Science, Technology, and Society/3-6

High Emphasis

4.5 Objective: Personal needs. The student shall understand that science and technology can affect individual lifestyles and that the individual, in turn, responds to affect science and technology.

Example Subobjectives	Example Activities
4.51 Technological developments affect the way students and members of their families work.	4.511 List ways that computers are used in work or business by parents or relatives of students.
	4.512 Identify special equipment in the school that would not have been available for students and teachers to use ten years ago (or when parents went to school).
	4.513 Ask a plumber, carpenter, or electrician what equipment or materials are used regularly that were not available five or ten years ago.
4.52 Technological developments affect the way people use their leisure time.	4.521 List new developments that students are using for entertainment (computer games, cable or satellite television, compact disk stereo, VCR). Consider this use of time compared to activities not requiring technology (outdoor sports, fishing).
	4.522 Discuss the effect air travel has had on family vacations.
4.53 Medical science and technology improve chances of good health and longer life.	4.531 Discuss experiences students have had when going to a doctor or pediatrician.
	4.532 Read about diseases that were dangerous to children in the past (tuberculosis, small pox, polio, red measles). Discuss the impact the change has had on the lives of individuals.
	4.533 Discuss experiences of students who have had surgery. Find out how many parents had tonsils or appendixes removed when they were children.
	4.534 Write a story about what it will be like when people live an average life of 100 years.
4.54 Science and technology have made it possible to use unlimited amounts of energy.	4.541 Describe changes in home heating and cooling, transportation, entertainment due to easily available energy. Discuss alternatives to using large amounts of energy.
	4.542 List ways students can reduce the energy they use without giving up comfort or satisfaction.

Medium Emphasis

4.1 Objective: Attitudes and beliefs. The student shall understand that progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

4.11 The beliefs people held caused some early scientists to try to solve problems that could not be solved.	4.111 Find out what problems the early alchemists tried to solve.
	4.112 Describe the search for magic potions that could bring eternal life.
4.12 People with science knowledge have sometimes been persecuted by people with superstitious beliefs.	4.121 Discuss reasons people have been called witches or warlocks.
	4.122 Find out how very early medical research was done.
	4.123 Discuss the belief that understanding natural phenomena can bring bad luck.
4.13 Science knowledge has caused people to give up practices that were founded on superstition or fear.	4.131 List natural events that, once feared, are now easily understood (eclipses, volcanoes, tides, storms).
	4.132 Make a list of "old sayings" that controlled agricultural practice. Show how science and technology have become a better resource for agricultural decisions.

4.0 Science, Technology, and Society/3-6 (continued)

4.4 Objective: Societal needs. **The student shall understand that developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.**

Example Subobjectives	Example Activities
4.41 Science and technology have been a major force in changing the standard of living in the United States.	**4.411** Define standard of living and describe ways science and technology could influence it.,
	4.412 Take a field trip to a grocery store to discover products that have only recently become available.
4.42 The demands of society motivate scientists and technologists to produce new knowledge, services, and products.	**4.421** List pre-prepared foods in the grocery store. Decide why they have become available.
	4.422 Study safety features on automobiles. Find out when and why they became common equipment.
	4.423 Discuss nuclear power plants. Visit one if possible. Discuss why they exist and why there are not more of them.
4.43 Society, through representatives, puts controls on science and technology.	**4.431** Identify laws or regulations that control the ways in which certain products can be used (insecticides, fertilizers, fluorides in water).
	4.432 Discuss regulations controlling environmental pollution.

Characteristics of Students and Science Program

Students

Students at this age are developing social skills and have basic skills in language arts, arithmetic, and social studies. They are, perhaps, studying music. All of these areas contribute to studying science and can be used to further intellectual development in science, as well as science can contribute to growth in other basic areas. Students should begin to see science as a human invention, just as art, government, or religion.

Students begin to see science as a human invention . . . .

Program

- Problem solving has the highest level of emphasis. It focuses on asking questions and collecting data, with medium emphasis on analyzing and explaining the data.
- The science knowledge component is second only to problem solving, with high emphasis on diversity and change and medium emphasis on continuity and organization.
- The nature of science component places high emphasis on the variety of methods employed, and medium emphasis on the history of science and the comparison of science and technology.
- The science, technology, and society component places high emphasis on personal needs and medium emphasis on societal needs, attitudes, and beliefs.

Evaluation Tips

This level involves a range of four grades; the nature of students should be expected to change considerably over the period. Evaluation procedures should change accordingly. Informal practices can become more formal; the dependence on verbal responses can shift toward written responses.

Evaluation emphasis should reflect approximately the time allocations given to the four components. Teachers should avoid the tendency to emphasize testing the recall of factual knowledge over other levels of learning. Instead, they should emphasize evaluating students' abilities to apply processes related to problem solving. Students should demonstrate ability to observe and make measurements of length and capacity. They should be able to display measurements systematically in tables and simple graphs, and they should be able to communicate results orally, in written form, and with diagrams.

Avoid the tendency to emphasize testing the recall of factual knowledge over other levels of learning.

Evaluation at this level, or any level, must be tailored to a generalized level of student development. Just as teaching must challenge students but not require performance beyond their ability, testing must be limited to realistic tasks. Success on tests is important to maintaining interest in science. Therefore the level of difficulty should only be sufficient to discriminate between high and low achievers.

Success on tests is important to maintaining interest in science.

Evaluation of science knowledge at the 3-6 level should be restricted to the high and medium emphasis objectives—diversity, change, continuity, and organization. To agree with the students' characteristics, test items should be avoided that require high levels of abstract thinking. At the same time, tests should not dwell on facts. For example, if students have studied plants that are commonly used as food, the students' understanding of the plants, useful characteristics—the diversity of food plants—should be tested, rather than simple recall of the names of food plants.

Evaluating students' understanding of the nature of science and the interaction of science, technology, and society should be done with a combination of written test items and observation of participation in discussions and other class activities. Students at this level will be limited in their ability to propose solutions to social problems.

Curriculum planners and teachers should not hesitate to use group data to evaluate the effectiveness of the program. They should continually look for evidence of the activities that are not contributing to attaining the stated objectives, and be ready to make curriculum changes on the basis of student response rather than teacher preference.

The Middle/Junior High School Science Curriculum

Middle/Junior High School Overview
Curriculum Development in Middle/Junior High
Problem Solving—Middle/Junior High
Science Knowledge—Middle/Junior High
Nature of Science—Middle/Junior High
Science, Technology, and Society—Middle/Junior High
Evaluation—Middle/Junior High

Middle/Junior High School Overview

Middle/junior high school science should contribute to the development of scientifically literate persons and not simply prepare students for the next science course. The students should continue to develop science problem-solving skills and understandings. Middle/junior high school science courses should relate problem-solving skills and science knowledge to students' personal lives, and enable students to begin examining societal issues having a scientific and technological basis. In order for science experiences to have lasting value, students need to apply new skills and knowledge. Instruction should include laboratory and field activities that stress application and extend inquiry skills as a means of obtaining knowledge and resolving problems.

In order for science experiences to have lasting value, students need to apply new skills and knowledge.

Middle/junior high school students should receive science instruction for one full period for each day at school. Of this science instructional time, a minimum of 30 percent should be directed toward teaching the nature of science and the science, technology, and society components. At this level, these components take on a much greater emphasis than they received before. It is at this age that students begin to analyze situations and make affective judgments about issues.

According to studies of the intellectual development of children, most students in the middle/junior high school begin to use transitional thinking patterns. These students often approach problems in a concrete, hands-on manner, but occasionally may express ideas with abstract symbols and explanations. Class activities should be planned so that the students have many opportunities to discover cause-and-effect relationships. They should also experience examples of activities requiring more formal reasoning, without the teacher expecting total success.

This section is written for students with the learning characteristics of those in grades 7-9. However, with reasonable adaptation, this material is appropriate for students within any organization of grades in middle or junior high schools.

Curriculum Development in Middle/Junior High

Five options for developing a K-12 science curriculum are presented in section 4 of this guide. In addition, section 5 contains a procedure for curriculum development and worksheets to assist in that process. These sections are necessary preliminaries to developing a middle/junior high school science curriculum.

After choosing a curriculum development option curriculum planners should include the following consideration in the development process.

- The middle/junior high school science curriculum should be an integral part of the district K-12 science curriculum. It should be based upon the skills and knowledge developed in grades K-6, and form the basis for the science curriculum in the senior high school.
- The science curriculum in these grades should not be a miniature senior high school curriculum, but should reflect the interests and problem-solving skills of middle/junior high school students. There are model programs developed with National Science Foundation funds available for study or use that emphasize this characteristic.
- The completed curriculum should reflect the time allocations outlined for each of the four components of science education (see table 9, p. 28). Note the suggestion that equal amounts of science instructional time be devoted to developing problem-solving skills and teaching science knowledge—35 percent each.
- Of the 22 major objectives of a K-12 science curriculum, 11 are given high emphasis in the middle school/junior high school grades. Seven other objectives are given medium emphasis.
- Few of the learners in these grades solve problems by formal thinking processes, so activities should be planned that develop concepts with hands-on laboratory experiences. The lab experiences should be used to present new concepts and abstract ideas.
- All students will benefit from a multisensory curriculum that includes field trips, demonstrations, and audiovisual aids for teaching science concepts.
- At this age, students should be involved in doing investigations that require them to think about variables and controls.
- Teachers should feel free to use activities that require the students to use the problem-solving skills listed in this guide for grades 3-6. These are basic and should be continuously reinforced.
- Science instruction should be related to the students' personal lives. The students' science experiences should teach them that science is a vital part of the world.
- Outside resources should be used to gather ideas for classroom activities. Resources include other science teachers in the district, commercially available manuals, and publications such as *Science Activities* and *Science Scope*.
- No curriculum is perfect. Curriculum planners should not strive for perfection nor expect it. However, the science curriculum should be continually revised and improved.

Emphasis on Objectives

Recommended Time Allocation:
250 minutes per week

Total Relative Emphasis on Components

Problem Solving 35%
Science Knowledge 35%
Nature of Science 15%
Science, Technology and Society 15%

Component	High Emphasis	Medium Emphasis	Low Emphasis
1.0 Problem Solving	1.1 Ask questions 1.2 Collect data 1.3 Analyze data	1.4 Explain	
2.0 Science Knowledge	2.1 Diversity 2.2 Change 2.5 Organization	2.3 Continuity 2.4 Interaction	2.6 Limitation
3.0 Nature of Science	3.1 Evolution of science 3.2 Milestones 3.6 Science/technology	3.4 Accepted rules 3.5 Variety of methods	3.3 Assumptions 3.7 Creative enterprise
4.0 Science, Technology, and Society	4.4 Societal needs 4.5 Personal needs	4.1 Attitudes and beliefs 4.2 Economics	4.3 Politics

Developmental Problem-Solving Skills

Basic activities should involve students in

- predicting unknown data from data that are known (extrapolate)
- understanding a thought sequence based on simple logic (A leads to B, B leads to C, then A leads to C)
- dealing with simple abstract ideas
- visualizing simple models prepared by someone else
- discovering cause-and-effect relationships
- intuitively dealing with proportions

. . . AND ALSO . . .

provide exposure to basic senior high school activities

- attacking problems systematically
- using a logical thought process as part of their normal thinking pattern
- making a formal hypothesis which includes a possible cause and predicts a possible outcome
- designing controlled experiments
- foreseeing all combinations of variables in an experiment
- including mathematical relationships in conclusions and expressing proportional relationships

BE AWARE that students of this age have difficulty

- *making a formal hypothesis which includes a possible cause and predicts a possible outcome (if . . . then reasoning)*
- *devising their own controlled experiment*
- *predicting possible sources of error in an experimental design*
- *building their own models*
- *solving problems using proportional relationships*

Evaluation

Can students

- demonstrate independence in conducting investigations?
- measure and use quantitative data?
- show awareness and knowledge of the diversity, change, and organization of their environment?
- show an interest in science as it may affect their lives and careers?
- relate cause to effect?
- describe the way science, as a human enterprise, has developed?
- relate their personal interaction with science and technology to the interaction of the whole of society?

Does the program

- provide science instruction for every student for one full period every school day?
- relate to the characteristics of early adolescent students rather than characteristics of science disciplines?
- provide transitional and some formal reasoning experiences?
- motivate students to use their process skills in true investigations?
- introduce the nature of science and the science, technology, and society components as a major part of the science curriculum?
- emphasize scientific literacy for all students?
- include a systematic evaluation plan for reviewing program effectiveness?

Problem Solving—Middle/Junior High

Middle/junior high school students should be fully accustomed to working in a laboratory situation.

By the time students reach the middle/junior high school, they should be fully accustomed to working in a laboratory situation. They should be competent in recognizing patterns in events that lead to questions that can be answered by investigation. The students should be able to observe carefully and to use simple measuring devices. They should be able to organize data and do some analysis of measurements using simple applied mathematics.

At this level, problem solving is reduced to 35 percent of the total time allocated for teaching science. However, this time allotment should not be considered as independent of the time devoted to science knowledge; the two components should be closely interwoven. The laboratory becomes a useful tool in instruction to reach knowledge objectives. The problem-solving objectives continue to be important and evaluation of achievement related to these objectives must continue.

The problem-solving objectives continues to shift toward high emphasis. Data analysis becomes increasingly important as students' measurement and mathematics skills progress. By this time, most students should have mastered the simpler processes, or specific actions, that make up the overriding problem-solving objectives, and new emphasis can be put on more difficult processes. This does not mean that those skills that have been acquired should not continue to be used. Acquired skills must be used continuously as new and more sophisticated skills are developed. In the following table the specific actions in bold type should receive the greatest attention in the middle/junior high school grades.

■ Middle/Junior High School

Problem-Solving Action Groups

Questioning ↔	**Collecting Data** ↔	**Analyzing Data** ↔	**Explaining**
Noting patterns	**Observing**	**Predicting**	**Describing**
Noting discrepant events	**Measuring and quantifying**	**Inferring**	**Defining**
Seeking information	**Identifying significance**	Graphing	**Interpreting**
Formulating questions	Selecting variables	**Tabulating**	Developing mental models
Generating hypotheses	**Estimating**	**Using numbers**	Developing physical models
		Correlating	Communicating
		Classifying	

The specific actions in **boldface** type are to be emphasized at the middle/junior high school level.

Laboratory experiences at the middle/junior high school level should continue to build competence, as well as confidence, in problem solving. The major differences from the elementary school level should be the increasing sophistication of the tasks to be undertaken and the integration of several specific actions, or processes, into more complete investigations.

It is assumed at this level that laboratory activities will involve application of a variety of processes integrated into partial or complete investigations. For this reason, instead of example activities to go with objectives and subobjectives, examples of process components follow. These example components, and others, can be used by curriculum developers to design laboratory investigations.

1.0 Problem Solving—Middle/Junior High School

High Emphasis

1.1 **Objective: Ask questions.** The student shall ask answerable questions about nature.

Example Subobjectives		Example Activities	
1.11	Noting patterns. The student shall see relationships among objects and events.	1.111	Perceive similarities and differences in a set of objects.
		1.112	Perceive reoccurring events.
		1.113	Perceive persistent behaviors.
1.12	Noting discrepant events. The student shall note exceptions to patterns.	1.121	Look for unexpected results.
		1.122	Compare single events to related patterns and note differences.
		1.123	Use prior knowledge to identify unusual organisms, objects, or events.
		1.124	Compare actual to predicted results.
1.13	Seeking information. The student shall study objects or events (or descriptions of them) to ask informed questions.	1.131	Identify relevant observations.
		1.132	Verify personal experiences.
		1.133	Locate sources of information.
		1.134	Use sources of information to develop inferences.
1.14	Formulating questions. The student shall use initial information to ask questions that are structured so that they can be answered by investigation.	1.141	Ask meaningful questions.
		1.142	Separate theoretical questions from questions that can be answered by experience.
		1.143	Ask questions confined to observations that can be made.
		1.144	Separate broad questions into parts which, when answered, will contribute to a comprehensive explanation.
1.15	Generating hypotheses. The student shall use information and questions to generate statements that describe expected results of investigation.	1.151	Distinguish between guessing and predicting.
		1.152	Use repeated observations of an event or result to predict the next occurrence of the event or result.
		1.153	Structure questions that require only a positive or negative response.
		1.154	Make simple statements (hypotheses) that can be tested.
		1.155	State hypotheses in forms that suggest the variables to be observed or measured.

1.2 **Objective: Collect data.** The student shall collect pertinent data from nature.

1.21	Observing. The student shall make accurate observations of objects and events using the senses or using instruments to aid the senses.	1.211	Distinguish the physical properties of objects directly or by manipulating or changing objects to observe their properties.
		1.212	Choose appropriate instruments to aid the senses in making observations.
		1.213	Make observations without making inferences or drawing conclusions.
		1.214	Repeat observations to verify them or establish consistency.
		1.215	Refine observations by measuring, ordering, comparing.
		1.216	Separate pertinent observations from those that are extraneous.
		1.217	Identify sources of error in making observations.

1.2 Objective: Collect data (continued)

Example Subobjectives	Example Activities
1.22 Measuring and quantifying. The student shall use standard measuring devices to collect data.	1.221 Order objects in terms of common properties such as volume (capacity), weight, temperature.
	1.222 Use the fundamental units of the metric system to measure.
1.23 Identifying significance. The student shall select data that are relevant and accurate.	1.223 Devise arbitrary units of measure and compare them to standard units.
	1.224 Measure rates of change.
	1.225 Choose appropriate instruments and methods for making specific measurements.
	1.231 Limit observations to those that are pertinent to the question under study.
	1.232 Identify the level of accuracy required for data to be useful in a specific situation.
	1.233 Describe limitations that exist in collecting data.
1.25 Estimating. The student shall use experience to estimate values of quantitative data.	1.251 Use comparison to estimate data.
	1.252 Recognize situations where estimated data can be used.
	1.253 Estimate fractions of units where measuring devices have limited accuracy.

1.3 Objective: Analyze data. The student shall analyze data.

1.31 Predicting. The student shall use observations and known information to predict events.	1.311 Describe the differences between predicting and guessing.
	1.312 Use repeated observations of an event to predict the next occurrence of the event.
	1.313 Use quantitative measurement as a means of improving the accuracy of predictions.
1.32 Inferring. The student shall use evaluation and judgment to make inferences based on observation.	1.321 Demonstrate that inference is based on observation.
	1.322 Develop an inference from a set of related observations.
	1.323 State cause-and-effect relationships from sets of related data.
1.34 Tabulating. The student shall increase the value of data by organization and systematic display.	1.341 Design charts and tables to display data.
	1.344 Design tables to relate measured values of dependent and independent variables.
1.35 Using numbers. The student shall use applied mathematics as a means of analyzing data.	1.351 Use arithmetic operations to combine quantitative data.
	1.352 Use simple equations to analyze related data.
	1.353 Combine repeated measures to calculate average (mean) values of given quantities.
1.36 Correlating. The student shall note related changes in variables.	1.361 Compare values of dependent variables as related values of independent variables are changed.
1.37 Classifying. The student shall use the characteristics of objects or events to group them by noting similarities.	1.371 Describe the difference between one-stage and two-stage classification schemes.
	1.372 Classify a set of objects (or organisms) using as many one-stage schemes as can be devised.
	1.373 Classify a set of plants (animals, objects) using a two-stage (or more) scheme.

1.0 Problem Solving—Middle/Junior High School (continued)

Medium Emphasis

1.4 Objective: Explain. The student shall use the results of analysis to explain natural phenomena.

Example Subobjectives		Example Activities	
1.41	**Describing.** The student shall use words, symbols, and diagrams to explain the results of an investigation.	1.411	Use a written narrative format to describe the process used to collect and analyze data and the resulting interpretation or result.
		1.412	Draw diagrams to explain how materials and apparatus were used in an investigation.
		1.413	Use numbers and arithmetic algebraic symbols to show how collected data have been analyzed.
1.42	**Defining.** The student shall use the common characteristics of sets of objects or events to develop definitions that include the members of those sets.	1.421	Differentiate between general and operational definitions.
		1.422	Use data and the analysis of data to develop and refine operational definitions.
		1.423	Identify the limitations of a given operational definition.
1.43	**Interpreting.** The student shall use the results of analyzing data to interpret the meaning and significance of an investigation.	1.431	Inspect data tables to find systematic changes in variables.
		1.432	Compare the results of data analysis to the expected results and determine reasons for the differences.
		1.433	Allow for error in interpreting results.

Science Knowledge— Middle/Junior High

In the middle/junior high school science program, compared to the elementary level, the heavy emphasis on problem-solving objectives is decreased while the emphasis on knowledge objectives is increased so that the two components get balanced treatment—35 percent each of total instructional time. At this level, concepts not only provide a knowledge context for problem-solving activities, but become primary objectives for laboratory investigations. Students should now have sufficient laboratory competence to begin meaningful investigations that will lead to concept learning. The science knowledge and problem-solving components should be closely integrated as progress is made toward objectives in both areas.

At this level, concepts become primary objectives for laboratory investigations.

Common practice in the middle/junior high school is to offer year-long courses in life science, physical science, or earth science. This practice is acceptable because there is an abundance of examples of concepts for each of the six broad conceptual objectives recommended in this guide. However, an integrated approach—choosing examples from all subject areas—helps teachers avoid the tendency of teaching the subjects rather than the students. It is far more important to choose examples because they are appropriate to the learning ability of students than because they are part of the traditional structure of a particular science discipline.

■ Middle/Junior High School

Science Knowledge

Diversity. Natural phenomena display a wide variety of similarities and differences.

Change. The natural environment is constantly undergoing change.

Continuity. There is constancy in cause-and-effect relationships which makes change explainable.

Interaction. The interactions of matter and energy determine the nature of the environment.

Organization. Related systems within systems comprise the universe.

Limitation. Natural phenomena are limited by the fundamental nature of matter and energy.

All students at this level should have a full year of science each school year. It is not recommended that other subjects—such as health, safety, sex, or drug education—receive instructional time that should be devoted to science education objectives. These special subjects can be interrelated with science teaching, but it is important that objectives be organized for each area, with a full measure of instructional time allocated to the science objectives.

Students at this level are able to manage a much greater array of intellectual tasks than they could in earlier years. For this reason, only limitation objectives are kept in the low emphasis category. Organization objectives are given high emphasis. The overall effort is greatly increased to make the broad conceptual schemes part of the thinking tools of students.

The characteristics of students must be kept in mind when choosing subobjectives . . . .

The characteristics of students must be kept in mind when choosing the subobjectives, or subconcepts, to make up the science knowledge component. Students should still be able to experience the phenomena they are studying. Teachers should avoid overemphasis on complex abstractions and mental models that cannot be directly investigated or demonstrated.

The following table gives only a few examples of subobjectives for the high and medium emphasis knowledge objectives. Many others exist; textbooks and other resources can be used to find those that are most appropriate to the particular teaching situation. The high and medium emphasis objectives should be considered in the context of all six objectives for the science knowledge component.

2.0 Science Knowledge—Middle/Junior High School

2.1 Objective: Diversity. The student shall understand that natural phenomena display a wide variety of similarities and differences.

Example Subobjectives	Example Activities
Biological Science Examples	
2.11 Organisms are grouped according to previously developed criteria that are generally accepted.	2.111 Make collections of organisms (plants, leaves, insects) and name them using classification keys.
2.12 The criteria for grouping organisms are man-made and subject to change.	2.121 Construct arbitrary classification keys for sets of objects or groups of similar organisms.
2.13 Organisms may be classified using secondary (less obvious) characteristics such as behavior patterns, cell structure, or reproductive methods.	2.131 Separate well known animals into groups according to special abilities (flight of birds, capturing prey, etc.). 2.132 Group a set of plants according to the characteristics of their seeds.
Physical Science Examples	
2.14 Elements, the simplest form of matter, have unique characteristics.	2.141 Classify a group of elements according to their states (solid, liquid, or gas) at room temperature. 2.142 Classify metals according to their reaction in dilute acid, color or sheen, relative weight.
2.15 Elements can be combined to form a large variety of forms of matter. These kinds of matter can be broken down into the original elements.	2.151 Observe a variety of synthesis reactions (iron rusting, sulfur burning). 2.152 Observe decomposition reactions (hydrolysis of water).
2.16 Energy may be classified as potential, kinetic, or radiant. Energy can be changed from one form to another.	2.161 Identify a list of examples of each form of energy. 2.162 Develop an operational definition of radiant energy. 2.163 Change energy from one form to another.
Earth Science Examples	
2.17 The variety of rocks results from differences in mineral composition and history of formation.	2.171 Examine a variety of rocks and record similarities and differences. Attempt to explain the way the rocks were formed.
2.18 Landscapes reflect diverse climates and local earth history.	2.181 Compare aerial photos and topographic maps of local areas. Find evidence of the effect of climate and environmental forces on different landscapes.
2.19 There is a great variation in the surface structure of the planets.	2.191 Study actual photographs of the planets produced by N.A.S.A. Speculate on conditions on each planet.

2.2 Objective: Change. The student shall understand that our environment is constantly undergoing change.

Biological Science Examples	
2.21 Living things have changed in form, appearance, and complexity over time.	2.211 Examine fossil records (photos or real fossils) and compare to present related species. 2.212 Study recorded evidence of species that have existed in Wisconsin.
2.22 Developing new inherited characteristics may result in greater survival value for the species.	2.221 Investigate the ability of soil organisms to produce antibiotics. Describe the survival value of this characteristic.
2.23 Changing earth conditions cause changes in biotic communities.	2.231 Note changes with seasons (migration). Find evidence of long-range climatic effects on biological communities.
Physical Science Examples	
2.24 When the forces applied to matter are changed, some of the properties of the matter may be changed.	2.241 Study the effect of weights hanging on springs or on thin horizontal metal rods. 2.242 Study the effect of force on changing the position or speed of objects.
2.25 Changes involving matter and energy are either physical or chemical changes.	2.251 Show several examples of both physical and chemical changes and identify which occurred, stating how visible change is related to energy exchange.

2.0 Science Knowledge—Middle/Junior High School (continued)

2.2 Objective: Change (continued)

	Example Subobjectives		Example Activities
2.26	In a change of phase, energy is gained or lost by matter without a corresponding change in temperature.	2.261	Have students measure the temperature of a beaker containing crushed ice and water every 30 seconds until the temperature reaches 5°C. Relate length of time at 0°C to energy required as ice melts.
2.27	Changes which take place between particles within molecules or within crystals of matter are called chemical changes. Chemical changes always involve energy exchanges.	2.271	Illustrate examples of chemical changes (burning a candle, dissolving ammonium chloride in water, mixing baking soda and vinegar, flashing a flash bulb). Identify the form of energy that is involved and whether energy is gained or lost by the involved matter.
	Earth Science Examples		
2.28	Different earth materials are weathered at different rates.	2.281	Compare the ability of sandstone, limestone, and quartzite to withstand abrasion.
		2.282	Study local ravines or gorges to determine why they were formed.
2.29	Changes in solar radiation causes changes in seasons.	2.291	Observe globes in a darkened room with a central light bulb "sun" to model the effect of earth movement on length of day and the resulting total radiation on a given latitude.
		2.292	Measure the areas of the shadow of an object (vertical post) at different times during a day. Predict the temperature effect from the changing area for the same incident radiation.

2.5 Objective: Organization. The student shall understand that related systems within systems comprise the universe.

	Biological Science Examples		
2.51	Survival of living organisms is dependent on the complementary functioning of their organs.	2.511	Study the effect of kidney failure on the human body and treatment by dialysis and/or replacement (transplant) of kidneys.
		2.512	Study the function of the thyroid gland and the related reason for adding iodine to table salt.
2.52	Specialized cells in living things are modified to perform special functions.	2.521	Compare the shape of vacuous cells in the human body. Contrast shape with function.
2.53	Complexity in organisms is a matter of degree of specialization and interaction of the organs of an organism.	2.531	Dissect a variety of organisms (earthworm, crayfish, fish, frog) and compare the complexity of internal structures.
	Physical Science Examples	2.541	Construct an electric circuit involving a switch, light, battery, and conductors. Describe the function of each component.
2.54	Mechanisms made up of subsystems control the interaction of matter and energy.	2.542	Build a system of simple machines that work together to lift a weight. Involve as many machines as possible.
2.55	Electrical properties of matter are related to the distribution of electric charges.	2.551	Study a variety of ways to produce static electric charges. Compare "strength" of charges with an electroscope.
		2.552	Make a simple electric cell. Use it to show that moving electric charges (electrons) can do work.
	Earth Science Examples		
2.56	The earth's crust is made up of a few basic materials organized in many ways.	2.561	Using the periodic table of the elements and the chemical formulas for common rocks, identify those elements that make up most of the earth's crust.
2.57	The planets in the solar system move in the same direction around the sun in roughly the same plane.	2.571	Visit a planetarium for a demonstration of planetary motion.
		2.572	Construct a model of the solar system. Consider the magnitudes of planet size to distances from the sun.
2.58	The earth's crust is divided into several rigid plates which are slowly moving.	2.581	Construct cardboard and paper models to demonstrate sea floor spreading and continental collisions (subduction).

Medium Emphasis

2.3 Objective: Continuity. The student shall understand that there is a constancy in cause-and-effect relationships which makes change explainable.

Example Subobjectives	Example Activities
Biological Science Examples	
2.31 Cells contain genetic material that carries inherited traits.	2.311 Use films or video tapes to learn the structure and function of the cell nucleus.
2.32 Characteristics are inherited by offspring from the parent generation in definite predictable patterns.	2.321 Study the work of Gregory Mendel.
	2.322 Use fruit flies to demonstrate patterns of inheritance.
Physical Science Examples	
2.33 In a chemical change, matter and energy are conserved. The number of atoms of each element remain the same.	2.331 Weigh two substances before and after chemical combination (dissolution of sugar or salt in water can be used). Note that volume is not conserved.
2.34 Energy is conserved in a moving system.	2.341 Consider the change from kinetic to potential energy in a moving pendulum. Describe what happens to the energy as the pendulum slows and stops.
Earth Science Examples	
2.35 The earth has a magnetic field that remains constant for long periods of time.	2.351 Use a compass, a free hanging bar magnet, or a free moving coil with an electric current to demonstrate the presence of the earth's magnetic field.
	2.352 Demonstrate the potential energy of a magnet that is not aligned with the earth's field.
2.36 The moon's appearance (and position) changes in a regular and predictable way.	2.361 Consider the cause of the phases of the moon. Predict the position of the moon compared to the zenith at any time (hours, days, months) in the future.
	2.362 Calculate the number of degrees the moon moves in its orbit in one day.

2.4 Objective: Interaction. The student shall understand that the interaction of matter and energy determine the nature of the environment.

Biological Science Examples	
2.41 Green plants use energy from the sun and water and carbon dioxide from the environment to produce food.	2.411 Test the leaves of plants (geranium) for starch prior to and after exposure to sunlight.
2.42 Biological communities tend toward a balanced condition. This balance can shift over time as resources or conditions change.	2.421 Set up a pond water culture to show the changing balance as organisms interact.
Physical Science Examples	
2.43 Force is necessary to change the speed or direction of moving objects.	2.431 Use a variable incline to study the effect of gravitational force on a rolling ball.
	2.432 Study the forces on an object swung by a string in a circle (horizontal plane). Consider what happens when the string breaks.
2.44 Chemical and physical changes depend on the special properties of the substances that interact.	2.441 Classify substances that will or will not react with oxygen, dilute HCl, water.
Earth Science Examples	
2.45 Tides result from the interaction of the earth, moon, and sun as their relative positions change.	2.451 Construct a model to show the relative positions of the earth, moon, and sun at high and low tide.
2.46 Weather is the result of the interaction of masses of air at different temperatures and pressures.	2.461 Use data from weather maps to explain changing weather conditions on given days.

Nature of Science—Middle/Junior High

Middle/junior high school students have sufficient science knowledge and experience with problem-solving activities to appreciate events from the past . . . .

The nature of science should begin to have real meaning for middle/junior high school students. They have sufficient science knowledge and experience with problem-solving activities to appreciate events from the past and to understand the difficulty early scientists experienced when little was known, beliefs and superstitions dominated most people's thoughts, and the technology that could be applied to investigation was almost nonexistent.

The history of science can receive major consideration at this level. The traditional content—such as the discoveries of Kepler, Copernicus, Galileo, and Newton—should be included to convey the evolution of science. Studying modern developments helps students understand that certain discoveries in the early twentieth century have opened many new areas of research. The concurrent development of science and technology and their related knowledge brings meaning to students who are beginning to have a total impression of the nature of science.

■ Middle/Junior High School

Nature of Science

- *History of Science*

  Evolution of Science. The knowledge and processes of science have evolved over a long period of time.
  Milestones. Science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

- *Philosophy of Science*

  Assumptions. Science is based upon assumptions about nature.
  Accepted Rules. Scientists operate within a generally accepted set of rules.

- *Actions and Interactions of Scientists*

  Variety of Methods. Scientists use a variety of methods to solve problems.
  Science/Technology. Science and technology are interdependent activities.
  Creative Enterprise. Science is a creative enterprise.

At the middle/junior high school level, learning about the nature of science can be easily integrated with science knowledge, where the ideas presented have much broader application than before. Although there will seldom be a reason to develop whole lessons or units devoted solely to the nature of science, approximately 15 percent of the time devoted to science should be devoted to this component. Teachers can take advantage of current events in science, new discoveries, and technological advances to approach the objectives that are to be emphasized.

The evolution of science, milestones, and science/technology are the three areas that should receive high emphasis at this level. The variety of methods used by scientists is given somewhat less emphasis as more complex science ideas are introduced. The concept of accepted rules by which scientists tend to work is elevated to medium emphasis at this level. The remaining objectives—assumptions, and creative enterprise—are reserved for emphasis in the senior high school.

Take advantage of current events in science, new discoveries, and technological advances . . . .

3.0 Nature of Science—Middle/Junior High School

High Emphasis

3.1 Objective: Evolution of science. The student shall understand that the knowledge and processes of science have evolved over a long period of time.

Example Subobjectives	Example Activities
3.11 Early science developed from the observations of natural philosophy.	3.111 List as many facts as possible that could have been accurately observed before the tools and processes of science (telescope, microscope, measuring tools) were developed.
	3.112 Identify beliefs, assumptions, and social prohibitions that limited the ability of early observers.
3.12 Early conclusions about nature were made from logical deduction rather than from empirical, inductive investigation.	3.121 Describe the limitations of deductive reasoning as a means of understanding nature.
	3.122 Discuss the importance of collecting and analyzing all available data in drawing conclusions.
	3.123 Make a list of early explanations that were rejected when new results from empirical investigations were developed.
3.13 Mathematics was an essential development for the evolution of science.	3.131 Write a story about what scientific investigation would have become if there had never been a development of mathematics as a tool for studying nature.
	3.132 List the ways that mathematics is used in science.
3.14 The evolution of science is an important factor in the cultural development of the human race.	3.141 Compare progress in science with progress in other areas of human endeavor—art, music, literature, politics, economics, religion.
	3.142 Find examples of limitations in early societies (Egypt, Greece, Rome) because of lack of scientific knowledge.
3.15 The evolution of science can be attributed to a relatively small number of people who were able to overcome dogma and tradition.	3.151 Develop a list of people who are best known for advancing science prior to the 20th century. Put them in chronological order and indicate their major achievements.

3.2 Objective: Milestones. The student shall understand that science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

3.21 There have been long periods of time when there was almost no progress in understanding nature. These periods often coincide with lack of development in other areas.	3.211 Try to find evidence of development in science between the 5th and 13th centuries (the Dark Ages). Explain the result of this search.
3.22 Single accepted theories have revolutionized the contemporary thinking of the time.	3.221 Describe the conflict that resulted when Copernicus proposed that the sun, not the earth, was the center of the solar system.
3.23 The most important accepted theories have opened whole areas for new research and development.	3.231 Describe outcomes that may have resulted from Newton's law of gravitation, Huygen's theory of the wave nature of light, Einstein's theory of special relativity.
	3.232 Find the major theories that started the fields of research called nuclear physics, genetic engineering.
3.24 Important developments in science have had corresponding surges in new technology for continued study in the area.	3.241 Search for information about the development of special research equipment (nuclear particle accelerators, giant radio telescopes, super-conducting metallic rings).

3.6 Objective: Science/technology. The student shall understand that science and technology are interdependent activities.

Example Subobjectives		Example Activities	
3.61	Both science and technology involve recognizing problems, using known information and proposing solutions.	3.611	Compare the work of research in physics and research in nuclear engineering. Determine how the two activities are alike and how they are different. Use case studies if possible.
		3.612	Develop operational definitions of both science and technology. Consider whether these are activities or the products that result from such activity.
3.62	The knowledge produced by science is used by technologists to produce new products.	3.621	Research the events in science and technology that, during World War II, led to development of the atomic bomb.
		3.622	List reasons that might exist for industries to employ research scientists.
3.63	The products of technology are used by scientists to produce new knowledge.	3.631	List ways that the ability to put satellites in space has led to new fields of research.
		3.632	List technological achievements that have been necessary to the progress that has been made in exploring the universe.

Medium Emphasis

3.4 Objective: Accepted rules. The student shall understand that scientists operate within a generally accepted set of rules.

3.41	Scientists are restricted to using evidence that can be collected directly or indirectly from nature. Imagined or distorted data must be rejected.	3.411	Describe what would happen if theories could be based on conjecture or desired outcomes.
		3.412	Study the results of the discovery of the Piltdown man.
		3.413	List the benefits of the study of phrenology, astrology.
		3.414	Describe the problems encountered in U.F.O. research.
3.42	Scientific investigations are done without bias and results are never predetermined.	3.421	List sources of pressure that might cause practicing scientists to distort their data to produce desired results.

3.5 Objective: Variety of methods. The student shall understand that scientists use a variety of methods to solve problems.

3.51	Each step in a scientific investigation depends on selecting relevant and effective processes.	3.511	Compare the decisions a scientist must make to those of a person selling a popular product.
		3.512	Describe the kinds of decisions a scientist must make in the process of an investigation.
3.52	Planned investigations must change as new information and interpretations require. No simple series of steps can always lead to a solution.	3.521	Study the record of the process by which a particular research project was conducted. Identify decision points where the plan for research was changed.

Science, Technology, and Society— Middle/Junior High

Middle/junior high school students are rapidly broadening their interests as well as their knowledge. They are likely to want to expand their thinking beyond personal and direct experience. The students should have opportunities to reflect on the consequences of actions of governments, industries, special interest groups, and other powerful influences that affect the interaction of science, technology, and society. They can begin to consider national and, to some extent, worldwide issues, although the major teaching effort should still be placed on understanding the science/technology developments that affect them, their families, and their community. The high emphasis objectives for this level are personal needs and societal needs. Medium emphasis is placed on attitudes, beliefs and economics. Political interactions are reserved for later treatment.

Students should have opportunities to reflect on the consequences of actions of governments, industries, special interest groups . . . .

■ Middle/Junior High School

Science, Technology, and Society

Attitudes and Beliefs. Progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

Economics. Science and technology influence economic growth which, in turn, affects the progress of science and technology.

Politics. Science and technology influence political processes which, in turn, affect the progress of science and technology.

Societal Needs. Developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Personal Needs. Science and technology can affect individual lifestyles and the individual, in turn, responds to affect science and technology.

Since students at this level are concerned about themselves and their relationship to others, they should have ample opportunity to identify and discuss issues among themselves. Teachers should look for ways that the students' growing knowledge and problem-solving abilities can be applied to resolving science-related issues—if not in reality, at least in their own minds. The strategy should be to use issues as vehicles for pursuing subobjectives, which in turn contribute to attaining one or more of the five major objectives for this component. Class activities should not be limited to information-giving by the teacher; instead, responsibility should be placed on the students.

Activities for this component should be designed to encourage students to use a range of mental operations so that they can grow in their ability to respond to issues, as well as understand the principles involved. In planning activities, it will be helpful to consider the following hierarchy of five levels at which students can be involved with the science, technology, and society component. Middle/junior high school students will have difficulty in participating at the higher levels of this hierarchy, but open-ended activities should give them opportunities to proceed as far as they can.

Encourage students to use a range of mental operations so that they can grow in their ability to respond to issues . . . .

Level 1: Receiving Information. The student is attentive to and has awareness of facts, conditions, and opinions.

Level 2: Responding to Information. The student actively participates by reading, writing, listening, or speaking while demonstrating interest in an issue.

Level 3: Assigning Values. The student demonstrates consistent, stable behaviors associated with his or her sense of appreciation and perception of worth related to an issue.

Level 4: Organizing Systems of Thought. The student plans and executes rational, responsible behaviors stemming from an internally consistent set of values.

Level 5: Characterizing a Life Philosophy. The student demonstrates pervasive, consistent, and predictable patterns of personal, social, and emotional adjustment based on an integrated system of values.

At this level students should spend approximately 15 percent of the time in science courses working with the interaction of science, technology, and society. The following table should help curriculum designers begin the process of structuring the science curriculum for this component.

4.0 Science, Technology, and Society— Middle/Junior High School

High Emphasis

4.4 Objective: Societal needs. The student shall understand that developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Example Subobjectives		Example Activities	
4.41	Environmental controls are established by society to limit the impact of technological practices and products on the environment.	4.411	Using a variety of information sources, develop arguments for and against the widespread use of nondegradable insecticides (DDT) in this country or anywhere in the world.
		4.412	Find out why the use of leaded gasoline (or paint) has been restricted.
		4.413	Investigate the community practice for disposing of sewage or solid waste. Decide whether that practice is the best possible for the community.
		4.414	Study the problems of acid rain in Wisconsin. Make a list of related recommendations that could be sent to the Wisconsin Legislature.
4.42	Often the products of science and technology are accepted and used by society before their real benefits or the problems caused by their use are fully known.	4.421	Make a list of products (drugs, foods, aerosol sprays) that have been widely used and then withdrawn from the market.
		4.422	Find out how much is known about low-calorie sweeteners and the effects of their use. Develop a class position on the marketing of these products.
		4.423	Identify several suspected carcinogenic (cancer-causing) products that have been (or are still being) sold.
4.43	The lifestyle in the U. S. has been greatly improved by applications of science and technology.	4.431	Describe the advantages that electronic devices have brought in the last 20 years. List the devices that are commonly used.
		4.432	Discuss advantages that have come from new medical technology.
		4.433	List advantages that have come from improved food processing, marketing, and packaging.
		4.434	Make a list of scientific and technological advances where the advantages outweigh the disadvantages.
4.44	When a societal need is defined, there is usually an effort made through science and technology to meet that need.	4.441	Discuss the way solutions were found for serious diseases that no longer are a problem (plague, polio, small pox) and the current searches for solutions to existing diseases (cancer, heart disease, AIDS).
		4.442	Investigate efforts that are underway to find new sources of energy (fusion, geothermal, search for fossil fuels).

4.5 Objective: Personal needs. The student shall understand that science and technology can affect individual lifestyles and that the individual, in turn, responds to affect science and technology.

4.51	The products of science and technology often become controls on individual lifestyles.	4.511	Use personal experience or case studies to accept or reject the preposition that "increasing use of information processing limits privacy and personal freedom."
		4.512	List products that students feel they cannot get along without. Find out which of these products were not available to parents or grandparents.
		4.513	Write an essay on the topic "People tend to choose convenience and comfort over good sense." Explain how technology might influence this tendency.

4.5 Objective: Personal needs (continued)

Example Subobjectives		Example Activities	
4.52	Science knowledge makes it possible to make wise decisions about lifestyles.	4.521	Describe the specific knowledge of the human body that is useful in deciding whether to smoke, drink alcohol, or use drugs.
		4.522	Make a display showing the effects of exercise on the body. Include clippings and advertisements from newspapers and magazines. Emphasize references to new scientific findings and research.
		4.523	Develop arguments for and against the statement that "The lifestyle of an individual is determined by the material things available rather than by the knowledge and wisdom of the individual."
4.53	Science and technology affect career choices and the kind of work people do.	4.531	Research the job titles that can be identified with the high technology industries.
		4.532	Describe changes that have taken place in agricultural jobs in the last 50 years. Explain why this has happened.
		4.533	List ways that new methods of communication (telecommunication, satellites, conference calling) have affected jobs and careers.
		4.534	Identify 10 jobs that have disappeared because of new technology. List 10 jobs that have been created.
4.54	Science and technology affect the way individuals use their leisure time.	4.541	Poll classmates to find the average amount of time an individual spends watching television, playing computer games, listening to stereo music.
		4.542	Describe the ways improved travel and communication have affected use of leisure time for vacations.
4.55	The decisions of individuals can affect the direction taken by science and technology.	4.551	Develop an action strategy that an individual could use to cause industrial research and development to meet a particular need.
		4.552	Describe ways that a citizen through elected representatives, can act to give direction, support, or limit progress in science and technology.

Medium Emphasis

4.1 Objective: Attitudes and beliefs. The student shall understand that progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

4.11	Unfounded beliefs and superstitions have made it difficult for scientists to keep open minds when approaching problems.	4.111	Study the history of the development of the telescope and its use to view the moon and planets. Identify the faulty explanations caused by strongly held beliefs of what was seen.
		4.112	Find examples where religious belief inhibited progress in science and technology.
		4.113	Discuss the problems that arose when it was discovered that the sun, not the earth, was the center of the solar system.
4.12	The attitude that science can solve all problems gives people a false sense of security.	4.121	Discuss the possibility that through science and technology the amount of energy available in the world will never be limited.
		4.122	List problems that science and technology may not be able to solve (disposal of nuclear waste, controlling world population, eternal life, traveling to distant galaxies).

4.0 Science, Technology, and Society—Middle/Junior High School (continued)

4.1 Objective: Attitudes and beliefs (continued)

Example Subobjectives	Example Activities
4.13 Science, based on empirical evidence, is different from pseudoscience which is based on belief.	4.131 Compare astronomy to astrology.
	4.132 Study the origins of pseudosciences such as phrenology and palmistry. Compare them to the formal study of parapsychology or mnemonics.
4.14 Science knowledge dispels superstition and fear.	4.141 Discuss how the scientific dependence on a cause for every effect is in direct opposition to magic, spiritualism, and voodooism.
	4.142 Make a list of common superstitions to which people tend to react to even though they have science knowledge.

4.2 Objective: Economics. The student shall understand that science and technology influence economic growth which, in turn, affects the progress of science and technology.

4.21 The progress of science and technology result in new and improved products and services which bring economic strength and higher standards of living.	4.211 Study the outcome of a new major product becoming available (calculators, computers, satellite communications). Decide who benefited, which nations progressed.
	4.212 Search for economic advantages that have come to the local community because of science and technology (new stores, industries, jobs).
4.22 Economic needs influence decisions to provide support to research and development in science and technology.	4.221 Discuss problems that might occur if scientific research was supported only if it had potential economic value.
	4.222 Find examples in history where need motivated scientific or technological development (for example, development of the steam engine, cotton gin).
4.23 Research and development often result in applications with great unexpected economic value.	4.231 Find a list of research projects being conducted at a university. Consider which projects seem to have little practical value. Then reconsider to find potential value in them. (Example: research on the mating habits of cockroaches led to a nontoxic way to control them.)

Characteristics of Students and Science Program

Students

Evaluation at the middle/junior high school level needs to be more sensitive than at the elementary or senior high school levels because of the rapid developmental changes taking place in students at this age. The ability to deal with abstract ideas, visualize three- dimensional objects, and formulate generalizations will be well developed in some students and only beginning to appear in others. It will be difficult or impossible for some students to deal with problems or activities that require higher levels of reasoning, even though they are of average or above-average general intelligence. Evaluation that assumes a full range of adult cognitive abilities will yield false information; this form of evaluation can label some students as having low ability when in fact they may have above-average ability, but have not yet developed these abstract reasoning abilities.

Students at this age level should also be formulating career interests and goals. Faulty evaluation procedures can provide students with mistaken signals on courses to elect and careers to explore or avoid. Evaluation procedures need to produce valid, reliable measures of learning outcomes, and yet accommodate individual differences in developmental abilities of the adolescent.

Program

The middle/junior high school science program is not just preparation for high school science courses, nor is it preparation for college science majors. The central purpose of the science curriculum is to help students develop intellectual abilities and skills in the four components of science education, and to continue the process of developing overall scientific literacy. Therefore, the central purpose of evaluation should be to provide information that will enhance learning and certify that the objectives specified for this level are being achieved. At the middle/junior high school level, problem solving and knowledge objectives receive equal attention—about 35 percent each of the allocated time for science instruction. This time will be devoted to working with the high and medium emphasis objectives in these two components. The nature of science component and science, technology, and society component each receive 15 percent of the time. The evaluation process must reflect this balance by having the same degree of emphasis. Teachers need to avoid the tendency to test only the knowledge component. Where necessary, they should give up a dependence on written tests and multiple choice items.

The nature of the learner and the teaching objectives should always be kept in mind while designing evaluation strategies.

Evaluation Tips

Valid and reliable information can be collected by a variety of methods. Evaluation may rely on the teacher's observation and professional judgment which can be just as legitimate as any written test. Alternatives to the usual written tests may include

- a checklist which may be a simple yes/no form or may represent skill levels such as 1 = inadequate, 2 = adequate, 3 = superior;
- laboratory reports including analysis and interpretation of data collected;
- performance tests in which students are required to do a selected section of a laboratory activity under teacher supervision.

Language usage presents an especially acute evaluation and learning problem at the middle/junior high school level. Science texts at this level introduce many new technical terms. Complicating this problem are textbooks using familiar words in a new, precise way. Weight, mass, velocity, heat, and temperature—words used casually in everyday language—take on meanings which may or may not be understood by the students. Therefore, evaluation items must be screened very carefully for language biases that could invalidate the data collected. This is especially true when working with students from families or neighborhoods where ethnic background and language barriers give words varied meanings. In addition, many students at this level have difficulty with abstract thinking and higher order thinking skills such as analysis and synthesis.

At the middle/junior high school level, observation of laboratory activities is especially important in judging how well students are progressing in the problem-solving component. Students should be able to demonstrate fundamental skills using measuring tools and equipment generally not available at the elementary school level. The laboratory offers the student an opportunity to apply learning that has taken place. When using the laboratory as a source of evaluation data, teachers should consider the football analogy: in football the coach judges the success of the players in terms of performance during the game, not in terms of how well they memorized the plays.

Evaluating the nature of science and the science, technology, and society objectives presents another special problem. Names, dates, and other facts can become part of the curriculum, and because such content is easily placed in written tests it could dominate evaluation. This should be avoided. Rather, teachers should use discussions and written essays to determine whether students have assimilated the stated objectives into their thinking. Since much of the teaching in these components requires discussion and comparison, evaluation should be based on the same skills. Admittedly, traditional science instruction has not relied on the essay exam for evaluation, but if these components of the curriculum are to be successfully implemented, science teachers will have to make this change.

The Senior High Sc[illegible] Science Curri[illegible]

11

Senior H[illegible]
Curriculum Devel[illegible]
Problem [illegible]
Science Kn[illegible]
Science, Technology, and S[illegible]
Eval[illegible]

Senior High School Overview

The separate science disciplines cannot be treated as separate, unrelated studies.

There is a tendency in traditional senior high school science programs to design courses according to the nature of the separate science disciplines. These courses are often unrelated and make few concessions to the nature of the learner. A strong K-12 science curriculum cannot afford to follow this tradition. The senior high school science program should use the same broad objectives used at earlier levels, with only the relative emphasis on the objectives changing. The separate science disciplines become the context for selecting subobjectives, especially in the science knowledge component, but they cannot be treated as separate, unrelated studies.

At the senior high school level there should be a conscious effort to avoid an over-emphasis on the science knowledge component. Even though knowledge at this level receives the greatest portion of the total time—40 percent—this is still less than the emphasis in many existing programs. The recommendation of this guide is that 60 percent of the total time, or the equivalent of three full periods per week, be devoted to the other three science components. This is likely to require many changes in school science programs, including a change in the traditional method of testing students, since the objectives for the problem-solving; nature of science; and science, technology, and society components must be evaluated as thoroughly as are the science knowledge objectives.

The selection of science courses in senior high school should meet the needs of all students. Since many students will only meet the minimum state graduation requirement of two years of science in grades 9-12, it is important that those two years represent a balance among the four components as well as among the biological, physical, and earth sciences.

According to studies of the intellectual development of children, some, but not all, of the students in high school should have reached the formal operational level. Class activities in science courses should be designed to allow those students to use their abstract thinking abilities, and to provide the others with thinking experiences that will allow them to progress from the transitional level to the formal operational level.

Curriculum Development in Senior High

Five options for developing a K-12 science curriculum are presented in section 4 of this guide. In addition, section 5 contains a procedure for curriculum development and worksheets to assist in that process. These sections are necessary preliminaries to developing a senior high school science curriculum. The option chosen for developing a senior high school program should be compatible with the option selected for other levels.

After choosing a curriculum development option, curriculum planners should include the following considerations in the development process.

- The senior high school science curriculum should be an integral part of the district K-12 science curriculum. It should be based on the skills and knowledge developed in the elementary and middle/junior high school.
- The senior high school science curriculum will represent the last experience many students will have with formal instruction. It should provide them with knowledge skills, insights, and values that will enable them to be scientifically literate individuals.
- The option exists in the senior high school science curriculum to integrate the various disciplines (biology, chemistry, physics, earth science) into individual courses of study.
- The completed curriculum should reflect the time allocations outlined for each of the four components of science education (see table 9, p. 28).
- Of the 22 major objectives of a K-12 science curriculum, 17 are given high emphasis in the senior high school grades. The remaining five are given medium emphasis.
- Teachers should remember that many high school students do not use formal thinking processes to solve problems. Class activities must include hands-on laboratory experiences to present new concepts and abstract ideas.
- A high school course of study need not consist of covering the contents of a textbook from the front cover to back cover.
- At this level, students should be involved in activities that require them to formulate hypotheses and plan controlled experiments to test the hypothesis.
- Activities should be continued that require students to use the problem-solving skills listed for elementary and middle/junior high school. These are basic skills and should be reinforced.
- Activities should be designed that help the students determine the mathematical relationships of data collected through experimentation.
- Outside resources can provide many ideas for activities. Resources include commercially available manuals and publications such as *The Science Teacher*, *American Biology Teacher*, and *Journal of Chemical Education*.
- No curriculum is perfect. Curriculum planners should not strive for perfection nor expect it. However, the science curriculum should be continually revised and improved.

Senior High School

Emphasis on Objectives

Recommended Time Allocation:
250 minutes per week

Total Relative Emphasis on Components

Component	Emphasis
Problem Solving	**20%**
Science Knowledge	**40%**
Nature of Science	**20%**
Science, Technology and Society	**20%**

Component	High Emphasis	Medium Emphasis	Low Emphasis
1.0 Problem Solving	1.2 Collect data 1.3 Analyze data 1.4 Explain	1.1 Ask questions	
2.0 Science Knowledge	2.1 Diversity 2.2 Change 2.3 Continuity 2.4 Interaction 2.5 Organization 2.6 Limitation		
3.0 Nature of Science	3.1 Evolution of science 3.3 Assumptions 3.4 Accepted rules 3.6 Science/technology 3.7 Creative enterprise	3.2 Milestones 3.5 Variety of methods	
4.0 Science, Technology, and Society	4.1 Attitudes and beliefs 4.2 Economics 4.3 Politics	4.4 Societal needs 4.5 Personal needs	

Developmental Problem-Solving Skills

Basic activities should involve students in

- using logical thought processes as part of their normal thinking
- making a formal hypothesis that includes a possible cause and predicts a possible outcome (if . . . then reasoning)
- designing a controlled experiment
- determining all combinations of variables in an experiment
- including mathematical relationships in conclusions
- expressing proportional relationships

. . . AND ALSO . . .

provide opportunities to students for

- practicing and refining their abstract problem-solving skills
- using concrete problem-solving skills if necessary

BE AWARE that although it is implied that formal abstract thought processes are present in the high school grades, not all high school students have attained this level of problem-solving skills.

Evaluation

Can students

- demonstrate competence in most laboratory skills?
- plan and conduct a complete investigation?
- show understanding of the six conceptual schemes in the three science subject areas?
- describe science by describing its history, philosophy, and methods?
- describe scientists as humans who have the same emotions, problems, and concerns as people in other enterprises?
- respond to the issues raised by the interaction of science, technology, and society by using accurate science knowledge?

Does the program

- offer students opportunities for independent investigation and learning?
- rely heavily on formal reasoning experiences?
- have the recommended emphasis on the four components of science education?
- provide opportunities for students who want to specialize in science while also providing scientific literacy for all?
- motivate students to continue learning in scientific and technological fields?
- encourage confidence and positive attitudes toward the study of science and technology?
- apply up-to-date apparatus and educational technology to classroom and laboratory teaching?

Problem Solving/Senior High

In senior high school, most students should be competent in applying problem-solving processes and have confidence and motivation to proceed on their own in the laboratory. Some students are likely to have fallen behind in building their problem-solving skills, but if this component has had proper emphasis in the previous years, most students can work independently in the laboratory.

At this level, problem solving should be used as an important tool for both demonstration and investigation of the concepts of the science knowledge component. Until now, knowledge was primarily the context in which problem-solving objectives were pursued. Now the problem-solving skills that students have developed should be used extensively to build understanding of the increasingly complex knowledge component.

The problem-solving skills that students have developed should be used to build understanding . . . .

Further development of the problem-solving component is largely a matter of instructional sophistication. With better laboratory equipment and instrumentation, data gathering requires new techniques and increased precision. The data analysis processes requires better use of mathematics, and explaining requires use of language skills and systematic reporting.

At the senior high school level, only 20 percent of science class time is recommended for actual instruction devoted to improving problem-solving skills. This does not mean that use of the laboratory should be limited to the same percentage of time; the laboratory can be used in teaching all four components. The "ask questions" objective is reduced to medium emphasis at this level because it has had major attention earlier. The other three objectives, or process categories, will have high emphasis, within time constraints, throughout the senior high school science experience. Students should strive for increased competence in skill learned earlier as well as in new practices. They should be aware of the similarities between their laboratory work and that of practicing scientists. Related to that awareness should be awareness of career possibilities in science and technology requiring the skills that have been developed.

The following table indicates by boldface type the specific actions, or processes that should receive the most attention at this level. These are the only processes that will be used in the guide's examples.

To the greatest extent possible, students at this level should make decisions as to how they will proceed in their investigations. Teachers should avoid dominating students' actions in the laboratory by using activities with too many directions.

Problem-Solving Action Groups

Questioning ↔	Collecting Data ↔	Analyzing Data ↔	Explaining
Noting patterns	Observing	Predicting	Describing
Noting discrepant events	**Measuring and quantifying**	Inferring	Defining
Seeking information	**Identifying significance**	**Graphing**	**Interpreting**
Formulating questions	**Selecting variables**	**Tabulating**	**Developing mental models**
Generating hypotheses	**Estimating**	**Using numbers**	**Developing physical models**
		Correlating	**Communicating**
		Classifying	

The specific actions in **boldface** type are to be emphasized at the senior high school level.

The table that follows indicates the objectives and examples of subobjectives for the problem-solving component. Examples of process components for each subobjective are given rather than examples of activities as was done for the elementary grades. At the senior high school level, laboratory work almost always involves an integration of processes into major problem-solving activities or investigations. However, when planning these activities teachers should consider the contribution each experience is making to the subobjectives that are involved.

1.0 Problem Solving/Senior High School

High Emphasis

1.2 Objective: Collect data. The student shall collect pertinent data from nature.

Example Subobjectives	Example Activities
1.22 Measuring and quantifying. The student shall use standard measuring devices to collect data.	**1.221** Use standard units of measure for all quantities.
	1.222 Use and prefer the MKS (metric) system of measurement.
	1.223 Choose the appropriate method and device for measuring specific quantities in specific situations.
	1.224 Measure or evaluate quantities that depend on more than one variable (density, pressure, velocity, momentum).
	1.225 Use indirect means to measure quantities.
	1.226 Use approved techniques with specialized measuring instruments.
	1.227 Recognize the limitations of use and precision of measuring devices.
1.23 Identifying significance. The student shall select data that are relevant and accurate.	**1.231** Select data that are directly related to the problem under investigation.
	1.232 Define relative error allowable for data according to the nature of the problem.
	1.233 Limit quantitative recordings to the number of significant figures necessary to the investigation and defined by the accuracy of equipment.
	1.234 Eliminate extraneous observations and effects.
	1.235 Identify limitations placed on an investigation by the senses, techniques used, equipment, prior assumptions, and sources of information.
1.24 Selecting variables. The student shall identify the variables acting on a phenomenon and select those to be observed in an investigation.	**1.241** Differentiate between constants and variables.
	1.242 Differentiate between dependent and independent variables.
	1.243 Select quantitative variables over qualitative variables to improve precision and objectivity.
	1.244 Devise methods for controlling selected variables.
	1.245 Establish boundaries within which variables can change during an investigation.
	1.246 Establish correlational change in variables.
	1.247 Use variables that can only be evaluated by indirect means, extrapolation, or estimation.
1.25 Estimating. The student shall use experience to estimate values of quantitative data.	**1.251** Extend accuracy of measurement by interpolation.
	1.252 Extend the limits of measurement by extrapolation using general tendency and plotted curves.
	1.253 Devise techniques for estimating inaccessible measurements (height of tall buildings, extremely high temperatures, very long, or very short periods of time).
	1.254 Use statistical methods to estimate data.
	1.255 Establish levels of confidence for estimated data.
	1.256 Use estimated data to formulate questions and hypotheses for more precise investigations.

1.3 Objective: Analyze data. The student shall analyze data.

Example Subobjectives	Example Activities
1.33 **Graphing.** The student shall use a variety of graphing techniques to expose patterns in data.	1.331 Use graphic displays, charts, histograms to display data.
	1.332 Use rectangular coordinates to plot correlated values of variables to show direct proportions.
	1.333 Graph linear relationships to determine constants of proportionality.
	1.334 Use rectangular coordinates to determine regular patterns in data (bell curves, quadratic functions, exponential growth or decay, trigonometric functions).
	1.335 Use rectangular coordinates to plot paired data to show statistical tendencies (scattergrams).
	1.336 Use spherical coordinates to plot position as a function of angle and distance.
	1.337 Use three-dimensional coordinates to establish relative position of points in space.
1.34 **Tabulating.** The student shall use tables, charts and matrixes to systematize data.	1.341 Devise charts and tables to systematically display data.
	1.342 Use tables to sort and organize data and results of analysis.
	1.343 Use matrixes to relate correlated data and results.
	1.344 Develop charts of criteria and examples for classificational schemes.
	1.345 Use charts or tables to show relationships between observations, inferences, and generalizations.
	1.346 Develop statistical tables relating data to group means, grand means, standard deviations, and variances.
1.35 **Using numbers.** The student shall use applied mathematics to analyze quantitative data.	1.351 Use arithmetic and algebraic operations to analyze data.
	1.352 Use numerical data in formulas and algebraic expressions to calculate values for derived quantities.
	1.353 Using appropriate symbols, derive formulas to describe phenomena.
	1.354 Use ratios and proportions to describe relationships among quantities.
	1.355 Use numerical analysis to demonstrate generalizations (conservation of mass or energy, mole concept, genetic probability).
	1.356 Apply statistical procedures to analyze group data.
1.36 **Correlating.** The student shall note related changes in variables.	1.361 Infer cause-and-effect relationships among variables.
	1.362 Identify cases of direct proportionality.
	1.363 Calculate constants of proportionality for direct proportions and relate constants to the slopes of linear curves.
	1.364 Relate energy changes to corresponding effects and, conversely, for each effect identify an energy exchange.
	1.365 Use statistics to infer group effects.
1.37 **Classifying.** The student shall use the characteristics of objects or events to group them by noting similarities.	1.371 Develop multistage classification schemes for large and varied sets of objects or organisms.
	1.372 Use standard classification keys to identify sample plants, animals, rocks.
	1.373 Use classificational systems as a resource for prediction and inference.
	1.374 Use classifications of chemical substances to identify the characteristics (toxicity, solubility, melting point) of selected substances.

1.0 Problem Solving/Senior High School (continued)

1.4 Objective: Explain. The student shall use the results of analysis to explain natural phenomena.

Example Subobjectives		Example Activities	
1.43	Interpreting. The student shall use the results of analyzing data to interpret the meaning and significance of an investigation.	1.431	Compare results of data analysis to prior knowledge and experience to make an interpretation.
		1.432	Use predicted sources of error to interpret anomalies in data.
		1.433	Interpret limitations of an investigation in terms of techniques, equipment, and resources used.
		1.434	Use evidence of dependence of variables to interpret cause-and-effect relationships.
		1.435	Interpret discrepancies or correspondence between anticipated results (hypotheses) and actual results.
1.44	Developing mental models. The student shall use information from resources or evidence obtained from investigations to develop mental models that explain phenomena.	1.441	Develop systematic and consistent patterns of thought to explain broad concepts.
		1.442	Describe the details of specific phenomena (reaction of chemical elements, photosynthesis, magnetic fields).
		1.443	Use oral or written narratives or diagrams to describe mental models.
		1.444	Extend accepted mental models when new evidence is presented.
		1.445	Combine mental models to form broad generalizations.
1.45	Developing physical models. The student shall build or describe physical systems that are analogous in structure or function to natural phenomena.	1.451	Use standard laboratory equipment to demonstrate specific phenomena (interference of waves, dispersion of light, convection, kinetic molecular motion, circulatory systems).
		1.452	Use kits or specialized materials to make physical models (organic molecules, electric systems).
		1.453	Design and construct models to explain results of investigations.
1.46	Communicating. The student shall use a variety of techniques to communicate the results of investigations to others.	1.461	Verbally describe results using scientific terminology.
		1.462	Use charts, tables, graphs, and diagrams to explain the results of investigations.
		1.463	Use systematic procedures to solve mathematical problems and derive equations so that others can follow the process that was used.
		1.464	Develop complete laboratory reports including hypotheses or questions under investigation, procedure for collecting data, process of analysis, and explanation of results.
		1.465	Defend, before critics, a conclusion reached as a result of an investigation.

Medium Emphasis

1.1 Objective: Ask questions. The student shall ask answerable questions about nature.

Example Subobjectives	Example Activities
1.14 Formulating questions. The student shall use initial information to ask questions that are structured so that they can be answered by investigation.	1.141 Separate questions that can be answered by empirical investigation from all other questions.
	1.142 Ask questions designed to extend knowledge.
	1.143 Develop a hierarchy of questions where one must be answered before the next can be undertaken.
1.15 Generating hypothesis. The student shall use prior knowledge and experience to generate testable hypotheses.	1.151 Translate questions into simple hypotheses.
	1.152 State hypotheses that identify variables to be manipulated.
	1.153 Differentiate hypotheses that can be tested quantitatively from those that are limited to qualitative tests.
	1.154 Design tests for given hypotheses.
	1.155 State negative or null hypotheses as a means to eliminating variables.
	1.156 Establish criteria and confidence levels for accepting or rejecting hypotheses.

Science Knowledge/Senior High

Science knowledge is the major thrust of the senior high school science program. Traditionally, however, many students do not take more than two years of science after they reach ninth grade. This is unfortunate because students are now at a level of intellectual maturity where they are best able to assimilate into their thought patterns the abstract relationships that characterize natural phenomena. This limitation on student exposure to science puts stress on the early senior high school courses to meet the nation goal of scientific literacy. Therefore, it is not reasonable to put most senior high school science resources into specialized courses in biology, chemistry, and physics which are taken by a minority of students. Developing highly effective courses for the early high school years should be a high priority among school districts. These courses, required of everyone, should make major contributions to scientific literacy.

Effective courses for the early high school years should be a high priority among school districts.

Science knowledge has, in the past, been the primary emphasis in senior high school science courses. This guide recommends that a change is needed in science education. Even though science knowledge is the primary emphasis, it is not the only emphasis. As at other levels, a balance among the four components of science education continues to be essential. Science knowledge objectives should receive 40 percent of the available instructional time, leaving 60 percent of the time to be divided equally among the other three components.

Along with establishing the proper balance among the four science components it is necessary for science curriculum developers to be committed to considering the nature of the learner first and the structure of the disciplines second. The traditional disciplinary high school science course has little respect for the learner. Even though it may be expected that a high percentage of students will be able to reason at the formal level, there is evidence that an emphasis on descriptive lectures is not an effective teaching method. It follows that the use of problem-solving skills in the laboratory is necessary in the teaching plan for the science knowledge component. An important consideration in choosing knowledge content at this level is the degree to which concepts can be adapted to laboratory investigation.

Consider the nature of the learner first and the structure of the disciplines second.

All concepts cannot be learned in the laboratory. The six knowledge objectives (conceptual schemes) are important to apply when choosing abstract explanations and theories to present in science classes without laboratory reinforcement. Using this criterion helps to limit content to basic foundational concepts. The six knowledge objectives should be reviewed for their interrelationships. At this level, all six knowledge objectives will receive high emphasis. The process of selecting subobjectives that contribute to these broad umbrella concepts can be made easier when it is understood that even in senior high school there is no need to cover the entire knowledge of the science disciplines. It is only necessary to have sufficient examples of the broad concepts to build general understanding.

There is no need to cover the entire knowledge of the science disciplines.

Science Knowledge

Diversity. Natural phenomena display a wide variety of similarities and differences.

Change. The natural environment is constantly undergoing change.

Continuity. There is constancy in cause-and-effect relationships which makes change explainable.

Interaction. The interactions of matter and energy determine the nature of the environment.

Organization. Related systems within systems comprise the universe.

Limitation. Natural phenomena are limited by the fundamental nature of matter and energy.

The following table gives examples of subobjectives that are appropriate for senior high school in the three major areas: biological, physical, and earth science. Use these examples as guides for selecting the total content of the courses that make up the senior high school science program.

2.0 Science Knowledge/Senior High School

2.1 Objective: Diversity. The student shall understand that natural phenomena display a wide variety of similarities and differences.

Example Subobjectives		Example Activities	
	Biological Science Examples		
2.11	Diversity in organisms is due to differences in the chemical composition of the genetic material of cells.	2.111	Use photographs (electron microscope, if possible) to identify cell chromosomes.
		2.112	Describe the concept of genes as areas on chromosomes.
		2.113	Identify the chemical nature of the proteins that make the structure of DNA possible. Discuss variations that can occur in DNA molecules.
		2.114	Investigate the cause of specialization of cells within an organism.
2.12	Variation among species is passed on from generation to generation within the same species.	2.121	Study the eastern and western meadow larks. Decide whether there is really a genetic difference in them.
		2.122	Determine the difference between species and races.
		2.123	Identify the inherited characteristics that are the primary differences in similar species (deer mice and shrews, ocelots and pumas, pythons and boas, myrtle and palm warblers).
2.13	Genetic differences in species allow them to adapt to different environments. Some species have very specific environmental requirements.	2.131	Find out why Kirtland's warbler is so rare.
		2.132	List reasons that at the present time so many species are on the endangered list.
		2.133	Do a plant population count in a square meter of prairie. Repeat in the same size plot at the boundary of the prairie and a woodlot.
		2.134	Study the populations of plants on a bank of a new road-cut. Compare to the bank of an older road.
	Physical Science Examples		
2.14	Kinetic potential and radiant energy appear in a variety of forms.	2.141	Compare radio waves, infrared radiation, visible light, and ultra violet radiation. List similarities and differences in the effects they cause.
		2.142	Identify similarities and differences among a mass at a fixed height, a magnetic pole at a fixed position in a magnetic field, and an electric charge at a fixed position in an electric field.
		2.143	Investigate the energy transfer that occurs when a light bulb lights, a piece of paper burns, a rock falls, a pendulum clock ticks.
2.15	Most of the physical properties of matter result from forces acting on the basic particles of matter and the relative energy of the particles.	2.151	Explain change of phase in terms of kinetic molecular motion.
		2.152	Develop an hypothesis to explain the difference between ionic and metallic crystals.
		2.153	Identify sources of both kinetic and potential energy in matter.
		2.154	Develop a model to demonstrate the difference between good electrical conductors and good insulators.
		2.155	Describe the difference between forces that hold electrons to atoms and the binding forces of the nucleus.
2.16	The chemical elements show systematic similarities and differences that are the basis for the periodic chart of the elements.	2.161	Develop an explanation for the similarities of the vertical columns of elements in the periodic chart (the metals, halogens, inert gases).
		2.162	Study the similarities of sulfur and oxygen, silicon and carbon, potassium and sodium. Develop an explanation for these similarities.
		2.163	Develop alternative charts of the elements that are different from the standard periodic charts. (Use alternate systems of classification.)

2.1 Objective: Diversity (continued)

Example Subobjectives		Example Activities	
Earth Science Examples			
2.17	Landscapes reflect the diversity of climate, rock type and structure, and past history.	2.171	Discover evidence of dramatic change in the landscape of Wisconsin. (Glacial effects, mountain remnants, monadnocks.)
		2.172	Compare aerial photographs and topographic maps of areas with very different landscapes to find evidence of the effect of climate, rock type, and structure on geologic history.
		2.173	Using written resources, develop a geologic history of Wisconsin that explains the driftless area, central golden sands area, and granite of the northern highlands.
2.18	The diversity of rock-forming minerals is the result of the unique chemical properties of silicon.	2.181	Identify the family of elements that includes silicon. List the properties of silicon that make it different from others in the family.
		2.182	Build styrofoam models of possible silicon–oxygen frameworks and compare them to the known crystal structures of various silicate minerals.
		2.183	Conjecture what the earth would be like if it were not for the simple fact that silicon and oxygen combine to form silica.
2.19	The diverse role of water on the planet results from its abundance and its chemical-physical properties.	2.191	Study actual streams or use a stream table to obtain specifications on the ability of streams to transport earth materials.
		2.192	Evaluate the fact that water expands as it freezes and the effect this has on the earth's surface.
		2.193	Determine the approximate percentage of the earth's surface that has been altered by water in the form of glaciers.

2.2 Objective: Change. The student shall understand that our environment is constantly undergoing change.

Biological Science Examples			
2.21	Evolution is the major theory that explains the changes over time in living species.	2.211	Develop a history of the theory of evolution, including the controversy that has arisen over this important theory.
		2.212	Find examples of the principle of the survival of the fittest.
		2.213	Compare the Lamarkian theory of evolution with the Darwinian theory.
2.22	Mutations occur when the genetic material of an offspring is different from that of parent organisms.	2.221	Discuss the probability that a mutation will produce an individual that will have an advantage over others of the same species.
		2.222	List known as well as possible causes of mutation.
		2.223	Investigate genetic diseases that are actually mutations.
2.23	Changes in biological systems correspond to changes in their environments.	2.231	Find examples of biotic systems that were changed by human intervention.
		2.232	Develop models to show how environmental change can lead to species extinction.
		2.233	Use one-celled animals to investigate ways that chemical changes in a cell's environment affect the activity of the cell.
		2.234	Demonstrate that changes that occur in the life cycles of organisms are caused by changes in their internal and external environment.
2.24	Changes occur at all levels of biological organization.	2.241	Investigate changes that occur in living cells as they mature and age.
		2.242	Find examples of predictable change in biotic communities.
		2.243	Demonstrate that life forms have changed in complexity and appearance during the history of the earth.

2.0 Science Knowledge/Senior High School (continued)

2.2 Objective: Change (continued)

Example Subobjectives	Example Activities
Physical Science Examples	
2.25 Normally neutral aggregates of matter demonstrate electrical properties when exposed to an electric potential.	2.251 Measure the resistance and conductivity of wires made of different metals. 2.252 Diagram the charge distribution on a hollow metal sphere when it is moved to a variety of positions around a point charge. Substitute other hollow or solid metal shapes for the sphere. 2.253 Investigate the electrical properties of solutions and emulsions (a saltwater solution, an alcohol–milk emulsion).
2.26 The wavelength of radiant energy can be changed by changing the density of the medium through which it passes.	2.261 Demonstrate and describe the phenomenon of separation of white light into colors by glass prisms, rain drops. 2.262 Develop a model lens to demonstrate chromatic aberration. 2.263 Demonstrate mathematically that when the wavelength of radiant energy changes in a denser medium, there is a corresponding change in the energy of the photons.
2.27 Chemical changes always involve energy changes.	2.271 Demonstrate both exothermic and endothermic reactions. 2.272 Use a calorimeter to measure the heat of combustion of a variety of substances. 2.273 Using step reactions, calculate the enthalpy of reaction when a specified amount of methanol burns. Compare methanol to gasoline as an alternate fuel.
Earth Science Examples	
2.28 Erosion opposes volcanism and mountain building to constantly change the surface of the earth.	2.281 Use the theory of plate tectonics to explain volcanism and mountain building. 2.282 Find local evidence of uplifting and stress on rock formations. 2.283 Find local short-term and long-term evidence of water, wind, and ice erosion.
2.29 Climates in areas of the earth change with time.	2.291 Use fossil flora and fauna evidence to reconstruct climatic conditions that existed in a region when the flora and fauna lived. Compare to the present. 2.292 Describe conditions that must have existed in southwestern Wisconsin (the driftless area) during the last ice age. 2.293 Speculate on climatic changes that would occur in Wisconsin and Michigan if an uplift occurred that caused the Great Lakes to drain.
2.2(10) The seas of the earth are dynamic and constantly changing.	2.2(10)1 Find information on what is happening to the mineral content of the oceans. 2.2(10)2 Develop both flat maps and cross section maps to show the currents in the Atlantic ocean. Explain the forces that cause these currents. 2.2(10)3 Locate the major mid–oceanic ridges and deepest trenches. Explain their origin and the reason for their location.

2.3 Objective: Continuity. The student shall understand that there is constancy in cause-and-effect relationships which makes change explainable.

Example Subobjectives		Example Activities	
	Biological Science Examples		
2.31	Life forms closely resemble the parental forms from which they are reproduced.	2.311	Research the statistics that are available on the probability of mutation.
		2.312	Describe the mechanism by which DNA is replicated in reproductive cells.
		2.313	Study the origin of the theory of spontaneous generation. Speculate on why the theory was promoted and why scientists rejected it.
2.32	Organisms pass traits to their offspring through transmission of genetic material.	2.321	Identify characteristics among classmates that differ because they have inherited traits that result from differences in genetic material. Identify gross inherited traits that are the same for all.
		2.322	Describe the structure of chromosomes, genes, and related chemical systems that result in specialized cells.
		2.323	Compare the events of mitosis and meiosis. Explain the formation of chromosome pairs and the significance of dominant and recessive genes in determining the traits of offspring.
		2.324	Explain hybridization as a process that emphasizes genetic variation in a species.
2.33	Genetic traits and learned behavior combine to maintain the similarity between generations.	2.331	Discuss the proposition "Since the eastern and western meadowlarks differ only in song patterns, they differ only in learned or imprinted behavior and are the same species." Design an experiment to test this proposition.
		3.332	Identify examples of combined inherited and learned characteristics that are used to identify species (domestic pets, migrating birds).
		2.333	Discuss the reasonableness of the statement "Chickens don't fly long distances because their parents don't fly," or discuss the adventures of Jonathan Livingston Seagull.
	Physical Science Examples		
2.34	When energy is changed from one form or relationship to another the total amount of energy is conserved.	2.341	Use an elastic ball, allowing it to fall from a measured height. Calculate its potential energy relative to the floor before release, its kinetic energy just before impact, its loss of energy due to impact (absorbed). Calculate these values on successive rebounds and plot graphs to show the energy totals.
		2.342	Do energy calculations of a pendulum at several points in its swing. Plot curves for both potential and kinetic energy as a function of time. Explain the decreasing total energy as the pendulum swing damps.
		2.343	Apply Coulomb's Law to calculate the energy change of a fixed charge moving (by conductor) through a measured potential difference. Explain the loss of energy since energy is conserved.
2.35	In a collision between two masses both energy and momentum are conserved.	2.351	Use collision carts loaded with different masses to measure momentums before and after head-on collisions.
		2.352	Use pool balls or large steel bearings to collect data on collisions at angles. Treat momentum as a vector quantity and, if necessary, estimate angles and velocities.
2.36	The total amount of energy and mass remains unchanged in any molecular, atomic, or nuclear reaction.	2.361	Design and do investigations to test the laws of definite and multiple proportions.
		2.362	Use styrofoam models to show that in a chemical (ionic) reaction all particles are accounted for. Use bonding theory to account for all electrons.
		2.363	Use the mass/energy relationship (E = mc2) to explain the conservation of mass and energy in a variety of fission reactions.

2.0 Science Knowledge/Senior High School (continued)

2.2 Objective: Continuity (continued)

Example Subobjectives		Example Activities	
Earth Science Examples			
2.37	All objects in the solar system are moving in regular, predictable patterns.	2.371	Study the work of Tycho Brake and Johannes Kepler. Consider ways computers would have helped them.
		2.372	Use Newton's Law of Gravitation to calculate the force of attraction between the earth and moon. Calculate the speed (tangential velocity) that the moon must have to stay in its orbit.
		2.373	Explain the observed retrograde motion of the planets.
2.38	The climates of areas of the earth remain constant over long periods of time.	2.381	Identify general and specific factors that affect climate in the local area of the school.
		2.382	Contact the National Weather Service for information on variations in the climate of Wisconsin in the past 50 years.
		2.383	Study the effect climate has on vegetation, topography, population, surface and ground water in areas of the earth.
2.39	Rocks are layered in sequence with the oldest rocks found in the lowest layers of the sequence.	2.391	Determine the processes scientists use to determine the age of rocks.
		2.392	Find a site where a fresh vertical cut has been made through sedimentary rock. Reconstruct the history of the area.
		2.393	Find evidence that in rock layers the processes affecting the earth today also affected the earth in the past.
		2.394	Find ways the geological principles of superposition, uniformitarianism and fossil correlation were used to develop the geological time scale.

2.4 Objective: Interaction. The student shall understand that the interactions of matter and energy determine the nature of the environment.

Biological Science Examples			
2.41	Interaction of living organisms in a community results in the flow of energy and cycling of matter.	2.411	Identify several important predators and construct the food chains which make their existence possible.
		2.412	Demonstrate that the transfer of energy through living systems conforms to the second law of thermodynamics.
		2.413	Design experiments that could provide strong evidence that the same chemical matter in food becomes part of the substance of the consumer.
2.42	There is a continuous chemical interaction among the cells and organs of organisms.	2.421	Investigate the role of enzymes in providing energy to the cells of humans.
		2.422	Develop in vitro demonstrations of the specific actions of several enzymes on substrates.
		2.423	Investigate the chemical processes necessary to digestion and metabolism of carbohydrates in animal systems and individual cells.
2.43	Photosynthesis is the basic process that provides energy for life.	2.431	Develop an explanation for the apparent disagreement between photosynthesis and the second law of thermodynamics.
		2.432	Investigate the effect on the starch content of an area of a geranium leaf that is kept from light.
		2.433	Try to find examples of life forms that get energy from sources that do not include photosynthesis as the original process.

2.4 Objective: Interaction (continued)

Example Subobjectives		Example Activities	
	Physical Science Examples		
2.44	Force is the result of an interaction of matter.	**2.441**	Show that the result of the earth's attraction for any mass produces a constant acceleration (the acceleration of gravity).
		2.442	Determine the source of the forces that hold molecules or ions together in crystals (Van der Waal's forces). Estimate the magnitude of these forces in a variety of crystals.
		2.443	Use Hooke's Law to measure the interaction of a hanging mass (strain) causing distortion of a spring (stress). Plot force vs. distortion.
		2.444	From a plot of force vs. distortion of a spring, calculate the gain in potential energy of the spring as the area under the curve.
2.45	The interaction of atoms to form molecules or ionic crystals is due to forces between electric charges.	**2.451**	Describe the concept of electronegativity as it affects chemical bonds.
		2.452	Use diagrams or physical models to show the mechanics of ionic and covalent bonds.
		2.453	Analyze electron configurations to determine the probable formulas of a variety of compounds.
2.46	Force fields are the areas of influence around masses, electric charges, or magnetic poles.	**2.461**	Use a small magnetic compass to plot the shape of the magnetic field around a strong bar magnet.
		2.462	Determine the factors that affect electric current flow in a conductor moving in a magnetic field.
		2.463	Describe an electromagnetic wave in terms of energy and force fields.
	Earth Science Examples		
2.47	Variations in air temperature, density, and relative humidity combined with effects of the earth's rotation produce weather systems.	**2.471**	Develop a model system to demonstrate the Coriolis Effect. Use it to explain the interaction of the earth's rotation and the atmosphere.
		2.472	Explain the interaction of warm and cold air masses to produce cyclones, including the direction of rotation and reasons for cloud formation.
		2.473	Use the principle of conservation of angular momentum to explain the high velocity of winds in a tornado. Develop a three-dimensional model to describe the direction of winds and sources of energy in a tornado.
2.48	Angular velocity and gravitational force interact to produce the stable orbits of the moons and planets in the solar systems.	**2.481**	Knowing the distance to the moon and its angular velocity (6.28 radians every 28 days) calculate the mass of the moon.
		2.482	Speculate on the possibility of a large mass from outer space being captured in an orbit around the sun.
		2.483	Develop an explanation of the apparent fact that although gravitational force between objects in space attracts them directly toward each other, there are few collisions in space.
2.49	Interactions between the earth's crustal plates are constantly changing the earth's surface.	**2.491**	Determine the major reasons for accepting the theory of plate tectonics.
		2.492	Develop a model to show the effects of plate subduction.
		2.493	If Pangaea really existed, speculate on the reason all of the continental substance came together and what the forces are that tore it apart.

2.0 Science Knowledge/Senior High School (continued)

2.5 Objective: Organization. The student shall understand that related systems within systems comprise the universe.

Example Subobjectives	Example Activities
Biological Science Examples	
2.51 Biological systems vary in their degree of specialization.	2.511 Compare the simple structure of viruses and bacteria to the highly specialized cells of mammals.
	2.512 Find examples to show that cell specialization within an organism results in greater interdependence of cells.
	2.513 Study biological communities to find ways that specialized functions of species make the existence of other species in the community possible.
	2.514 Describe the specialized function of the human species in the total system of the biosphere.
2.52 Complementarity exists between structure and function in biological systems.	2.521 Identify the significance of the molecular substances (enzymes, hormones, DNA) in serving special functions in life forms.
	2.522 Study the structure of tissues in plants and invertebrate animals in relationship to the special function those tissues perform.
	2.523 Study Darwin's finches to show that external body structures of organisms tend to reflect an adaptation to an ecological niche.
	2.524 Compare the structure of special organs (kidney, lung, heart, intestine) to the function they perform. Find examples of vestigial organs that have no real function.
2.53 The organizations within biological systems have many similarities.	2.531 Try to find a life form that does not depend on nucleic acids as the genetic thread between generations.
	2.532 Identify properties that all living cells have in common.
	2.533 Speculate on the possibility that extraterrestrial life would have characteristics in common with life on earth.
Physical Science Examples	
2.54 The distribution of electrical charges in matter determines the nature of matter.	2.541 Use orbital theory to explain the different chemical properties of the elements.
	2.542 From studying the atomic structure of metals, explain why they are good electrical conductors, and how they differ from good electrical insulators.
	2.543 Explain the significance of the usual balanced electrical charge in matter and the natural tendency for an imbalance of charge to become balanced.
2.55 Matter exists in a hierarchy of organizational levels.	2.551 Discuss the organization of matter in the nucleus of atoms and the possibility that further fine structure of the nucleus is yet to be discovered.
	2.552 Discuss the organization of the cosmos and the relationship among galaxies. Compare the notion of a big bang to the notion of a steady-state universe.
	2.553 Describe the role of energy in determining the way matter can be organized. Investigate the possibility that any form of matter can exist independent of energy.
2.56 Energy has many forms of organization with matter as well as existing independent of matter as radiant energy.	2.561 List the ways that energy can be related to matter.
	2.562 Compare the explanation of radiant energy as waves to the quantum theory of radiant energy.
	2.563 Investigate the ability of matter to absorb radiant energy and the ability of matter to radiate energy.
	2.564 Study the changing effects that radiant energy has on matter as its wavelength (or photon energy) changes.

2.5 Objective: Organization (continued)

Example Subobjectives		Example Activities	
	Earth Science Examples		
2.57	The earth is structured in a system of spherical layers according to the density of the material in the layers.	2.571	Prepare a cross-sectional diagram of the earth indicating the nature (density, temperature, composition, phase) of each layer.
		2.572	Describe the dynamic and static conditions that exist between earth layers.
		2.573	Speculate on past changes in the structure of the earth and on changes that will probably take place in the future.
2.58	The earth's history is systematically recorded in rock layers in the earth's crust.	2.581	Search local areas for rock layers containing fossils. Estimate the age of the fossils.
		2.582	Study aerial and topographic maps for evidence of major events in earth's history.
		2.583	Explain the fact that in the semi-arid region of the Grand Canyon in Arizona there is sedimentary rock more than 1.5 kilometers thick.
2.59	Matter in the universe is organized in a hierarchy of interrelated systems from atoms to galaxies.	2.591	Consider the following poem in terms of the organization of the universe: All the fleas have littler fleas And on their back abide them And on those fleas still littler fleas And on ad infinitum.
		2.592	Study the structure of the Milky Way galaxy and compare it to the solar system's structure.
		2.593	Decide where in the universe, if anywhere, matter exists in a true state of equilibrium.

2.6 Objective: Limitation. The student shall understand that natural phenomena are limited by the fundamental nature of matter and energy.

	Biological Science Examples		
2.61	The ability of organisms to adapt to changes in their external environment is limited.	2.611	Study the limits of one-celled animals in pond water as salinity is gradually increased.
		2.612	Vary the environment of bean seedlings to determine their limitations (water, temperature, CO_2, light).
		2.613	Study the effect of varying nutrients given to laboratory rats. (Do not continue to the point where the animals suffer.)
2.62	Homeostatic mechanisms that control the vital processes of most animals function within definite limits.	2.621	Investigate the factors that control rate of breathing. Determine if increase in CO_2 has a greater effect on increasing the rate than does a decrease of O_2 in the blood.
		2.622	Investigate the limitation of heart rate as a mechanism for compensating for the effect of exercise.
		2.623	Study the advantage higher animals, especially humans, have because of their ability to regulate body heat. Consider the limitation of this ability.
2.63	Aging is a limitation on individual life, but has advantages for species.	2.631	Speculate on what would happen to life if aging were not a characteristic of almost all forms of life.
		2.632	Investigate the changes that take place in cells, organs, and organisms as they age.
		2.633	Study evidence that suggests that aging is a programmed genetic effect.

2.0 Science Knowledge/Senior High School (continued)

2.6 Objective: Limitation (continued)

Example Subobjectives	Example Activities
Physical Science Examples	
2.64 Energy is constantly dissipated from organized to disorganized states in the environment.	**2.641** Discuss the significance of the second law of thermodynamics.
	2.642 Account quantitatively for the distribution of energy as the swing of a pendulum decays (a vibrating string stops as a wave damps).
	2.643 Try to find an example of a process or event where the total energy gained by matter is greater than the total energy expended.
2.65 There are certain unyielding conditions (sometimes called laws of nature) that place limitations on natural phenomena.	**2.651** Collect data to show the range of temperature and pressure where Boyle's Law controls the volume of a fixed amount of a gas. Discuss the limits where Boyle's Law is no longer sufficient to explain the effect.
	2.652 Use Newton's 2nd law of motion to explain the fact that there is a constant acceleration of gravity at the earth's surface.
	2.653 Describe the limitation of the laws of conservation (energy, mass, momentum) on the mechanisms controlling the universe.
2.66 The energy levels of the external electron orbitals of atoms of the elements limit chemical phenomena.	**2.661** Explain why an atom in an "excited state" cannot be stable.
	2.662 Use orbital theory to explain the possible valences of the atoms.
	2.663 Determine the energy of formation (enthalpy) of a variety of compounds in order to explain the stability of the products of oxidation and reduction.
Earth Science Examples	
2.67 Conditions on the surface of the earth are limited by the amount of energy available.	**2.671** Study theories of the cause of the ice ages.
	2.672 Develop a model to demonstrate the greenhouse effect. Discuss the reasons for concern that the amount of CO_2 is increasing in the upper atmosphere.
	2.673 Compare the amount of energy being absorbed by earth from space to the amount radiated from earth to space. Account for the difference.
2.68 The long time period over which changes in the earth's surface occur limits the effects that can be observed directly.	**2.681** Study the indirect time measurements that were used to develop the geological time scale. Discuss the degree of confidence that can be given to these methods of determining earth history.
	2.682 Find examples of direct measurement used to collect data that support the theory of plate tectonics.
	2.683 Design a study that could be done to determine whether the earth's magnetic field has always been the same as it is now.
2.69 The ability to know and understand the universe is limited by the velocity of light.	**2.691** Discuss the concept of a light year as it pertains to receiving any kind of radiant energy from outside the solar system.
	2.692 Develop a way of measuring relative velocities using sound that is analogous to measuring the red shift used to measure the distance to other stars and galaxies.
	2.693 Develop an explanation of the limits on space travel to distant stars (especially those outside the Milky Way) based on the theory of special relativity.

The overriding goal in studying the nature of science at the senior high school level is to develop an appreciation for science and technology as human intellectual enterprises that have had impacts on the world—both good and bad. These impacts are so extensive that it is difficult for students to comprehend them. Senior high school students should continue to develop knowledge of the history of science in the context of the new science knowledge they have learned. Examples of exciting discoveries and applications of knowledge should be used to develop a sense of the roles science and technology have played in the past and their current, even more empathic roles. Students should not miss the opportunities to speculate on the ways science and technology will affect human existence in the future.

Students should develop knowledge of the history of science in the context of the new science knowledge they have learned.

Prior to senior high school, it was not productive to attempt teaching the abstract ideas that regulate the scientific enterprise. With the increased student ability for formal reasoning at this level, they all of the objectives for the nature of science component can be given high emphasis. However, because two of the objectives—variety of methods and milestones—have had considerable treatment at previous levels, they can be given medium emphasis so that more time can be devoted to achieving the objectives that are more complex.

■ Senior High School

Nature of Science

- *History of Science*

Evolution of Science. The knowledge and processes of science have evolved over a long period of time.
Milestones. Science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

- *Philosophy of Science*

Assumptions. Science is based upon assumptions about nature.
Accepted Rules. Scientists operate within a generally accepted set of rules.

- *Actions and Interactions of Scientists*

Variety of methods. Scientists use a variety of methods to solve problems.
Science/Technology. Science and technology are interdependent activities.
Creative Enterprise. Science is a creative enterprise.

Twenty percent of the time devoted to science instruction in senior high school should be given to this objective. Because this component is very important to scientific literacy—a goal for all students—it is necessary to make the nature of science a basic part of the courses required of all students or of the courses most students elect. However, this component, or any of the four science components, cannot be ignored in any course. The tendency to over-emphasize science knowledge cannot be justified, even in the specialized courses that only a few students can take.

While few textbooks include sections specifically titled "nature of science," there are numerous areas where these objectives can be easily introduced. For example, the basic assumptions about nature that scientists make are inherent in almost every knowledge area that is taught. Gas laws, as taught in chemistry and physics, are an ideal mechanism for getting at the assumption of causality. Consistency in natural phenomena is evident every time data are collected in a science classroom experiment. These opportunities must be used to relate what is being done or studied to the nature of science.

Students can analyze their own actions and decisions in such matters as designing laboratory work, comparing conflicting theories, and making value decisions.

Some of the objectives and subobjectives of the nature of science are more abstract than others. The philosophical nature of the material, and the fact that values and opinions are involved, suggest that open discussion will yield good results. Students can be required to analyze their own actions and decisions in such matters as designing laboratory work, comparing conflicting theories, and making value decisions. Curriculum planners and teachers should avoid designing isolated units labeled nature of science. The nature of science should be infused throughout the entire science curriculum. An isolated unit implies that when it is completed, "real" science will be taught.

Teaching the nature of science with activities can be done by analogy, using laboratory activities designed for problem-solving objectives. The curriculum designer should compare the objectives for teaching the nature of science to those identified for teaching problem-solving. Both kinds of objectives can be met using the same activities through questioning the basis for making decisions, validity of observations, and value of the results of investigations. The inquiries can be made using comparisons to what is known or believed to be the way that professional scientists would proceed. Such activities demand an awareness of the problems scientists must encounter.

Finally, subobjectives for this component must be stated explicitly, and specific ways need to be developed to evaluate each subobjective. Evaluation of objectives through testing, discussion, direct observation, or other forms of responses is essential to ascertaining that this component is being taught and learned.

3.0 Nature of Science/Senior High School

High Emphasis

3.1 Objective: Evolution of Science. The student shall understand that the knowledge and processes of science have evolved over a long period of time.

Example Subobjectives	Example Activities
3.11 The basic characteristic of science that separates it from other studies is the dependence on empirical observation.	3.111 Study the Greek philosophers to find the roots of experimentation.
	3.112 Consider the value of the syllogism as a way to analyze data. Consider the problems of Aristotelian logic.
	3.113 Compare experimentalism to intuitionalism. Identify the source of all scientific knowledge.
3.12 In science, the process of induction is more often used to analyze data than is the process of deduction.	3.121 Develop operational definitions for the processes of induction and deduction. Identify times when either could be used.
	3.122 Discuss the difference between theoretical science and empirical science. Find evidence for the change in relative dependence on these two approaches through the history of science.
3.13 The processes and knowledge of science have evolved from the inquisitive nature of the human mind.	3.131 Find examples of individuals who made important progress in science basically because of curiosity (Galen, Galileo, Count Rumford, Mendel).
	3.132 Read selected parts of "The Ascent of Man" by Jacob Bronowski. Discuss places other than Europe where the processes of science were beginning to emerge.
	3.133 Discuss the proposition: "Science is a process that was the natural result of a developing civilization."
3.14 New scientific or technological knowledge tends to raise questions that lead to further discoveries as science evolves.	3.141 Speculate on questions that were raised when bacteria were found to be the cause of infection, mosquitoes were found to be spreading malaria and yellow fever, viruses were first discovered as causes of disease.
	3.142 Write a paper on the effect of Darwin's theory of evolution on further biological research, the theory of plate tectonics on research in geology, the theory of special relativity on research in physics.
	3.143 Discuss the effect of the interrelatedness of knowledge on the nature of science and scientific research.
3.15 There are key individuals and special discoveries that have made science and technology controlling influences in the world.	3.151 Identify the 10 most important scientists or technologists in history. Consider the time in which they lived (Newton, Galileo, Maxwell, Einstein, Pauling, Darwin).
	3.152 Identify the 10 most important scientific or technological discoveries and consider when they happened (nuclear fusion or fission, the steam engine, vaccination, space travel, insect control).
	3.153 Discuss the following: "The importance of science is derived more from the understanding it brings than the products that, through technology, are made available."

3.3 Objective: Assumptions. The student shall understand that science is based on assumptions about nature.

3.31 The first truths of science must be assumed.	3.311 Describe the nature of assumption and determine when assumptions in science can be justified.
	3.312 Compare the axioms and postulates of mathematics to the basic assumptions of science.
	3.313 Explain the reasons that the roots of science began with natural philosophy.

3.0 Nature of Science/Senior High School (continued)

3.3 Objective: Assumptions (continued)

Example Subobjectives	Example Activities
3.32 It is assumed that the universe and all natural phenomena that comprise the universe are real and exist outside the minds of humans (reality).	**3.321** Discuss the concept of reality. Discuss the limitation of the senses in perceiving reality.
	3.322 Write an essay on the importance of the assumption of reality to the progress of science.
	3.323 Discuss the statement: "There is no reality in time or space—these are only concepts of the mind."
3.33 It is assumed that there is a consistency in nature that assures regularity in natural phenomena (consistency).	**3.331** Describe the dependence of science on consistent results for inductive tests of hypotheses.
	3.332 List examples of dependence on the consistency of nature in the everyday lives of people (sunrise, gravity, food production).
	3.333 Attempt to prove that those natural events that have always happened will happen again tomorrow or next year.
3.34 It is assumed that natural effects have natural causes (causality).	**3.341** Use the assumption of causality to refute arguments for belief in magic or astrology.
	3.342 Discuss reasons that scientists must assume that there are cause-and-effect relationships in all observable phenomena.
	3.343 Discuss the problems scientists might encounter in trying to study extrasensory perception.
	3.344 Try to find an example of an accepted event or happening that has no natural cause.
3.35 It is assumed that the human mind is capable of understanding all of the interactions of matter and energy in all living and nonliving systems (comprehensibility).	**3.351** Explain why it is necessary for scientists to assume that understanding in a new area of research is possible.
	3.352 Discuss other areas of intellectual pursuit where assumed comprehensibility does not seem as important as it is in science.
3.36 It is assumed that scientific investigations can be repeated to get the same results (repeatability).	**3.361** Discuss the way that the process of science depends on repetition of experiments as a means of verification.
	3.362 Study the many ways that the Michelson-Morley experiment has been repeated to verify the independence of the velocity of light from other motions.
3.37 It is assumed that there is always some degree of error in experiments and that results are always tentative (tentativeness).	**3.371** Study a variety of experiments to identify possible sources of error.
	3.372 Explain the concept of allowed magnitude of error related to a stated hypothesis. Explain confidence levels.
	3.373 Describe the tentative nature of scientific evidence and give reasons for the assumption that there is no absolute scientific proof.
3.38 It is assumed that all data and explanations that come from data are contingent on the validity of prior assumptions (contingency).	**3.381** Consider changes that would be made in the perception of the universe if it could not be assumed that all space is linear.
	3.382 Study the problems encountered in explaining planetary motion when it was assumed that the earth was the center of the system.
	3.383 List beliefs or theories that have been generally accepted about natural phenomena that may have introduced error in making explanations (either past or present).

3.4 Objective: Accepted rules. The student shall understand that scientists operate within a generally accepted set of rules.

Example Subobjectives	Example Activities
3.41 Theories in science are accepted only when there is sufficient, verified, empirical evidence to support the theory (empiricism).	3.411 Study the history of the empirical investigations that led to the acceptance of Einstein's theory of special relativity.
	3.412 Identify pseudosciences that are discredited because empirical evidence cannot be presented to support ideas or theories.
	3.413 Identify the evidence that has been accepted to support the understanding of the dual nature of light.
3.42 Scientific investigations are done without personal bias and results are never predetermined (open-mindedness).	3.421 Discuss the problem scientists, who are also human, face in keeping the rule of open-mindedness.
	3.422 Find examples where scientists manipulated data to obtain a desired outcome.
	3.423 Identify the motives that cause scientists to be honest (or dishonest) in reporting their research.
3.43 Scientists are obligated to seek the simplest possible solutions, the least complex explanations, and the most comprehensive results (simplicity).	3.431 From the history of science, find examples of unifying theories that simplified prior explanations.
	3.432 Study the effort that has been made to combine electric, magnetic, and gravitational attraction into one theory.
	3.433 Discuss the simplification in genetic theory that has taken place in the last 25 years.
3.44 Knowledge produced by pure science is developed without regard for social ethics or practical requirements (immunity).	3.441 Discuss the limitations on pure science and the probability that social responsibility can be kept out of scientific research.
	3.442 Consider the difference in the moral responsibilities of scientists and technologists.
	3.443 Describe the multiple roles that people in science play that must affect the decisions they make.
	3.444 Determine whether scientific immunity is the same now as it was in the 19th century.
3.45 When working to produce new knowledge, the scientist will select results that are useful in explanations and reject results that have been nonproductive (relevancy).	3.451 Describe situations where a scientist might have a reason to use or publish irrelevant results.
	3.452 Considering that most research is funded with a special purpose in mind, discuss the pressures that might exist to place unimportant findings above truly significant results.
	3.453 If the rule of relevancy were not followed by a particular scientist, explain the probable chain of events that would correct the problems that might occur.
	3.454 Discuss the problems that might exist in recognizing the relevancy of scientific results.

3.6 Objective: Science/technology. The student shall understand that science, technology, and engineering are interdependent activities.

3.61 Careers in science and technology have common characteristics.	3.611 Study the careers of individual scientists and technologists to determine what the fields have in common.
	3.612 Determine the extent to which invention enters into science and technology.
	3.613 Identify the tasks performed at a variety of levels in both scientific and technological fields.

3.0 Nature of Science/Senior High School (continued)

3.6 Objective: Science/technology (continued)

Example Subobjectives		Example Activities	
3.62	Science and technology provide mutual support in the processes of developing knowledge and providing new products and services.	3.621	Interview scientists to determine the kinds of technical jobs they perform in the course of their research.
		3.622	Interview research engineers to determine the scientific nature of their work.
		3.623	Determine ways in which scientists and technologists actually work together on major projects (new methods of energy production, space research, genetic engineering).
3.63	Although the major purpose of science is to seek knowledge, there is almost always an anticipated application of the result of scientific research.	3.631	Discuss the urgency of nuclear research during World War II.
		3.632	Study the research project led by Dr. Jonas Salk to use killed viruses as antigens for a polio vaccine.
		3.633	Estimate the frequency of current important applications of research results that were not predicted. Compare that estimate to what was happening 50 years ago.
3.64	Although the major purpose of technology is to apply knowledge to production of new goods and services, there is almost always a need to search for new knowledge to complete the task.	3.641	Discuss the research problems that might have arisen in building the first communications satellite (computer, scotch tape, catalytic converter).
		3.642	Write a job description for an inventor who might work for a major home appliance industry in the late twentieth century.
		3.643	Choose a specific product and learn the history of its development.
3.65	Individuals working in science or technology will have a variety of motives that may cause shifting among the roles of scientist, technologist, and lay citizen.	3.651	Study the roles played by Dr. J. Robert Oppenheimer.
		3.652	Discuss the effects experience as a businessperson might have on decisions when the same person works as a scientist or technologist.
		3.653	Consider reasons that important scientists have seldom used their prestige to seek political offices.

3.7 Objective: Creative enterprise. The student shall understand that science is a creative enterprise.

3.71	Science is a significant part of human culture, having aesthetic and humanistic as well as practical values.	3.711	Explain why scientists often feel that it is worth seeking knowledge only for the sake of knowledge.
		3.712	Defend or refute the following statement made by a scientist in 1961: "Science is the creation of scientists and every scientific advance bears, somehow, the mark of the person who made it."
		3.713	Identify examples of aesthetic or humanistic products of science (the periodic chart of the elements, a mathematical description of the mechanics of the solar system, the model of the DNA spiral helix).
		3.714	Discuss the role of science and technology in the architecture of the cathedrals of western Europe built in the 14th century.
3.72	The explanations of science can bring aesthetic value (beauty) to the nonscientist.	3.721	Discuss feelings that students have encountered when they have suddenly "understood."
		3.722	List scientific explanations that are often seen as beautiful by lay people (the nature of the cosmos, traveling at speeds near the velocity of light, the structure of the atom).
		3.723	Debate the proposition, "The beauty of nature is enhanced by the understanding of nature."

3.7 Objective: Creative enterprise (continued)

Example Subobjectives		Example Activities	
3.73	Society's demand for practical outcomes of scientific research retards creative science.	3.731	Compare the reasons for public sponsorship of artists to reasons for public support of science.
		3.732	Accepting that artists reject public criticism, explain why creative scientists usually do not.
		3.733	Discuss the differences and similarities of the images held by the public of artists and scientists.
3.74	A major difference in scientific and artistic enterprises is the nature of the product that results.	3.741	Compare the singular ownership of a work of art (sculpture or painting) to the plural ownership of scientific models or explanations.
		3.742	Compare the public use of works of art (viewing, reading) to the restricted public use of the works of science.

Medium Emphasis

3.2 Objective: Milestones. The student shall understand that science knowledge has, over time, accumulated most rapidly after acceptance of major new theories.

3.21	There have always been mind-set barriers that inhibit the thinking of all but the most creative thinkers (scientists).	3.211	Find examples in the history of science where the teaching of current beliefs has inhibited the thinking of society about natural phenomena.
		3.212	Study the origin of the medical process called bleeding. What brought the practice to an end?
		3.213	In the context of the controversy between religious dogma and empirical science, find examples of significant changes in public thinking due to demonstration of observable facts of nature.
		3.214	Discuss the inhibiting effect of the dependence on deductive reasoning by early natural philosophers on the probability of scientific breakthrough.
3.22	Major scientific breakthroughs provide new areas of research that could not have been considered for research before.	3.221	List areas of research and new findings that followed the Max Planck statement of the quantum theory.
		3.222	Identify the major research results that led to the field of study called genetic engineering.
		3.223	Speculate on probable areas where science research will be focused in the next decade.

3.5 Objective: Variety of methods. The student shall understand that scientists use a variety of methods to solve problems.

Example Subobjectives		Example Activities	
3.51	Scientists are constantly involved in making decisions about the processes they will use in their research.	3.511	Study the classic description of the scientific method. Discuss the reasons that this method must be varied depending on the problem being studied.
		3.512	List the kinds of decisions that must be made in designing investigations.
		3.513	Discuss the importance of choosing between relevance and irrelevance in doing an investigation.

3.0 Nature of Science/Senior High School (continued)

3.5 Objective: Variety of methods (continued)

Example Subobjectives		Example Activities	
3.52	In doing research, scientists must always be prepared to observe the unexpected.	3.521	Identify cases in the history of science where unexpected results have become major discoveries.
		3.522	Describe the decisions that must be made by a researcher who makes an unexpected discovery or observes a pattern in data that is unrelated to the problem being researched.
3.53	Empirical science requires that results be inferred from direct or indirect observation.	3.531	Describe some of the specialized devices that are used to make observations of subatomic particles.
		3.532	Find the applications that have been made of the process of electrophoresis spectrophotometry, interferometry, x-ray diffraction.
		3.533	Study some of the special measuring or observing devices used in laboratories (electron microscope, particle accelerator, laser).
3.54	Knowledge is expanded through a variety of reporting methods.	3.541	Obtain copies of a few scientific journals and study the methods that are used to report research findings.
		3.542	Determine whether there are ever restrictions placed on the ways that results can be reported by sponsoring agencies or industries.
		3.543	Study historical research reports and compare past procedures for expanding scientific knowledge to present procedures (reports of Joseph Priestly, Henry Cavendish, Isaac Newton, Charles Darwin, Galileo).

Science, Technology, and Society/Senior High

By the time students reach the senior high school, they have sufficient background in science and other subjects, as well the necessary intellectual skills, to progress beyond merely responding to the issues created by the interaction of science, technology, and society. Students at this level assign values to issues. Some relate values into systems of thought and alter their behavior to be consistent with their ideas. Simply providing information through discussion or reading is not enough. Issues should be provided that are sufficiently thought provoking to bring students to the point of decision making about their own actions and the actions of society as a whole. Curriculum planners and teachers should be aware of attainment levels for the objectives for this component.

Issues should be sufficiently thought provoking to bring students to the point of decision making . . . .

Level 1: Receiving Information. The student is attentive to and has awareness of facts, conditions, and opinions.

Level 2: Responding to Information. The student actively participates by reading, writing, listening, or speaking while demonstrating interest in an issue.

Level 3: Assigning Values. The student demonstrates consistent, stable behaviors associated with his or her sense of appreciation and perception of worth related to an issue.

Level 4: Organizing Systems of Thought. The student plans and executes rational, responsible behaviors stemming from an internally consistent set of values.

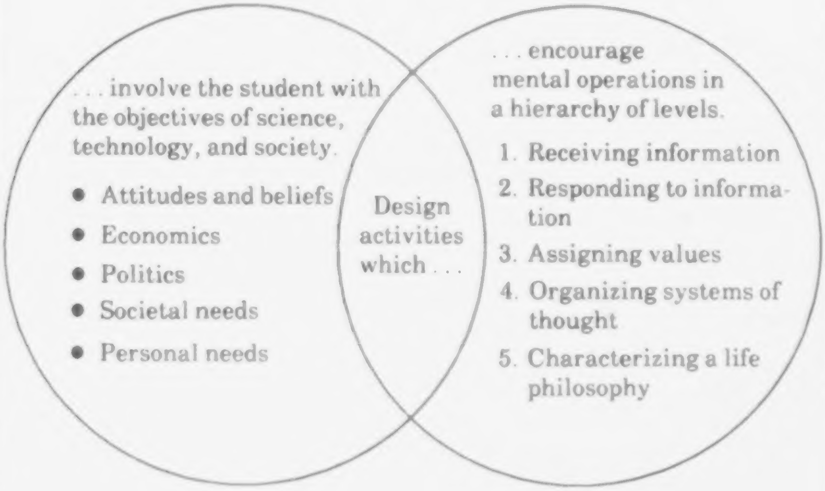
Level 5: Characterizing a Life Philosophy. The student demonstrates pervasive, consistent, and predictable patterns of personal, social, and emotional adjustment based on an integrated system of values.

Students in the middle/junior high school seldom are able to operate beyond the second or third levels in this hierarchy; but senior high school students should often have opportunities to reach level 4 and occasionally level 5. The hierarchy provides a framework for selecting and designing activities related to the specific component objectives while also leading students to higher levels of attainment. Clearly, the lower end of the hierarchy (receiving and responding to information) requires direct teaching methods, while higher levels are less tangible and require more innovative teaching and curriculum designs. Since senior high school is the last opportunity for formal science education for many students, it is very important that the necessary effort be made to design activities that will foster performance at the higher levels. At the same time, the component objectives must receive careful treatment. The table below shows the interaction of the five levels of the hierarchy with the five objectives.

Senior high school is the last opportunity for formal science education for many students; design activities that will foster performance at the higher levels.

■ Senior High School

Science, Technology, and Society/Mental Operations


. . . involve the student with the objectives of science, technology, and society.
● Attitudes and beliefs
● Economics
● Politics
● Societal needs
● Personal needs
Design activities which . . .
. . . encourage mental operations in a hierarchy of levels.
1. Receiving information
2. Responding to information
3. Assigning values
4. Organizing systems of thought
5. Characterizing a life philosophy

Students in senior high school courses should pursue the objectives related to the interactions of science, technology, and society for approximately 20 percent of science instructional time. The major teaching strategy should introduce science- and technology-related social issues and problems to which students can apply the knowledge and skills they have acquired in previous grades and courses. The high emphasis objectives are attitudes and beliefs, economics, and politics. The objectives for societal needs and personal needs that previously received high emphasis are now reduced to medium emphasis. As with the other three science components, none of the objectives are given low emphasis at this level.

■ Senior High School

Science, Technology, and Society

Attitudes and Beliefs. Progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

Economics. Science and technology influence economic growth which, in turn, affects the progress of science and technology.

Politics. Science and technology influence political processes which, in turn, affect the progress of science and technology.

Societal Needs. Developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Personal Needs. Science and technology can affect individual lifestyles and the individual, in turn, responds to affect science and technology.

A variety of group and individual activities can be derived from each issue that is introduced. The following table gives examples of issues rather than examples of activities for each sample subobjective. This differs from the way examples were presented in this guide for the science, technology, and society component at the other three instructional levels. The curriculum designer should determine specific activities.

4.0 Science, Technology, and Society/Senior High School

High Emphasis

4.1 Objective: Attitudes and beliefs. The student shall understand that progress in science and technology is controlled by the attitudes and beliefs of society which are, in turn, influenced by the progress of science and technology.

Example Subobjectives	Example Activities
4.11 Society's attitudes toward the environment and exploitation of resources control research and development.	4.111 Should public support be given to development of technology to extract large amounts of petroleum from oil-shale found in the Rocky Mountains?
	4.112 Will it be worth the necessary money and resources to build permanent orbiting space stations or bases on the moon?
	4.113 Do benefits outweigh potential problems in creating new life forms through the process of genetic engineering?
	4.114 Can society ultimately benefit from unlimited use of insecticides, herbicides, and other chemicals in the environment as a means to increase food production?
	4.115 Is it justifiable for the meat producing industry to research new ways to use hormones to increase production if there is a degree of danger from consumer reaction to residues?
	4.116 To what degree should industry be restricted in disposal of chemical, gaseous, solid, and nuclear wastes if restriction causes increased prices of goods and services?
4.12 Generally held beliefs, superstitions, and fears can put restrictions on the progress of science and technology.	4.121 Is it possible that too much knowledge can cause problems for our society?
	4.122 Should people distrust scientists and technologists and the products of their research and development?
	4.123 Are people ever justified in feeling that science research causes changes in weather patterns (cold winters, storms) or natural catastrophes (volcanic eruptions, floods, earthquakes)?
	4.124 Is there any danger in researching extrasensory perception, unidentified flying objects, black magic?
4.13 Much of society believes that science and technology can solve any national or world problem that arises.	4.131 Are scientists dedicated, altruistic people who devote their lives to solving the problems of society?
	4.132 What are the limitations on the possible achievements of science and technology?
	4.133 If the world environment were known to be approaching destruction would it be possible to move the human race to a new environment?
	4.134 Will humans ever exceed the speed of light, create mass and energy from a vacuum, eliminate the effect of momentum in collisions?
	4.135 Can science and technology always provide for the needs of an ever increasing world population?
	4.136 Will humans ever contact other intelligent life in the universe?
4.14 Knowledge produced through science and technology changes the thought structures of society.	4.141 Are the philosophies of Aristotle, Socrates, Plato obsolete?
	4.142 Is science a threat to organized religion?
	4.143 Can the family unit survive in a scientific/technological world?
	4.144 Will the worth of the individual diminish as society becomes more and more dependent on computers and robots?
4.15 The progress of science and technology has relieved society of the burden of ignorance and superstition.	4.151 Are the people of the U. S. better able to cope with the environment and natural events than people in third world countries?
	4.152 Is there ever reason to fear random and capricious (or intentional and directed) natural forces?

4.1 Objective: Attitudes and beliefs (continued)

Example Subobjectives		Example Activities	
4.16	The maintenance and protection of society requires philosophical advancement along with scientific and technological advancement.	4.161	Does human life continue when it is completely dependent on life support systems or artificial organs?
		4.162	Is it true that once a new control over life or the environment is possible it is impossible to keep that control from being used?
		4.163	Can society really control the advance of science and technology?

4.2 Objective: Economics. The student shall understand that science and technology influence economic growth which, in turn, affects the progress of science and technology.

4.21	The national economy is dependent on continuing scientific and technological research and development.	4.211	Should society reward scientists for successful research that has no immediate economic application?
		4.212	Should business and industry control the allocation of resources for scientific and technological research?
		4.213	Is the economic competition of the U. S. with other countries sufficient reason for our government to support private research and development?
		4.214	Should economic consideration be placed above the environment when decisions are made to carry out technological application.
		4.215	If a moratorium were put on scientific and technological research in this country, what would happen to the economy?
		4.216	Should public resources be used to support research that is conceived by and directed toward private profit?
4.22	A major part of the gross national product is put into research in science and technology.	4.221	Is industry justified in spending large amounts of money on research when some segments of society are demanding more support for social programs?
		4.222	What criteria should industries use in allocating funds for research and development?
		4.223	Does expenditure on research and development to expand the economy have as much effect on social welfare as direct spending on social assistance programs?
4.23	The total impact of developments in science and technology on the economy is seldom known at the time the development occurs.	4.231	What effect did the development of the transistor have on the economy in the first year it existed?
		4.232	What are the risks industries face when they invest in new developments?
		4.233	Would it be wise for economic decision makers to wait for a sure thing before investing in research and development?
4.24	Without economic growth, a high level of support for research and development cannot be sustained.	4.241	What priorities must a corporation consider in making expenditures when gross income is reduced?
		4.242	If corporate income, in general, begins to fall, should the government take over the investment in new research to stimulate the economy?
		4.243	What are the options for economic growth through application of technology in a developing country?
		4.244	Would it be wise to have scientists and technologists managing companies that are having trouble maintaining corporate income?

4.0 Science, Technology, and Society/Senior High School (continued)

4.2 Objective: Economics (continued)

Example Subobjectives	Example Activities
4.25 Developments in science and technology cause changes in processes from which economic strength is derived.	4.251 Is the advantage of scientific and technological research and development over the trial-and-error invention processes of the 17th and 18th centuries reflected in the status of our present society?
	4.252 Has the change from a dependence on heavy industries to dependence on high technology (electronics) been an elected option, or was it forced by new knowledge and processes?
	4.253 Should economists try to control the effect science and technology have on the development of new industries and industrial processes?
	4.254 Should scientists try to direct the changes that will happen in industry in the future?

4.3 Objective: Politics. The student shall understand that science and technology influence political processes which, in turn, affect the progress of science and technology.

Example Subobjectives	Example Activities
4.31 National political strength is enhanced by, if not dependent on, scientific and technological development.	4.311 Should a national emergency require immediate, all-out commitment of scientific resources?
	4.312 Is it justifiable to spend public funds on the education of scientists and technologists who, at government expense, realize great personal benefit?
	4.313 It is appropriate for government to use scientific and technological devices to monitor or intervene in highly personal matters (religious beliefs, sexual practices, interactions with friends and families) of citizens for purposes of national security?
	4.314 To what extent is the balance-of-power in the world dependent on technology to maintain military strength?
4.32 Government competes with other functions of society for control of science and technology.	4.321 Should government have the right to limit or discontinue a particular line of research?
	4.322 Is the scientific community more responsible to government than to other segments of society when it is government that funds much of the research?
	4.323 Should the purposes of government supersede those of industry for scientific resources, considering the importance of economic growth to society?
4.33 Governments use the developments of science and technology in a world competing for power and prestige.	4.331 What were the primary goals for the Appollo program that first put an astronaut on the moon?
	4.332 Was the first atomic bomb important only because it ended World War II?
	4.333 What political outcomes would be expected if the United States built the first successful nuclear fusion power plant?
	4.334 Should governments freely share their scientific and technological secrets?
4.34 Dependence on government funding for research causes a tendency toward political control over the research that can be done.	4.341 Should scientists, rather than politicians, be the national advisors to determine the criteria for funding research?
	4.342 Does the principle of academic freedom give scientists the right to pursue any research problem they choose?
	4.343 Considering all of the resources available to the government, does it follow that the government is in the best position possible to determine the direction research in science and technology should take?
	4.344 Are the needs for research and development as perceived by a democratic government usually the same as the needs perceived by the people whom the government serves?

Medium Emphasis

4.4 Objective: Societal needs. The student shall understand that developments in science and technology affect the condition of life, and, in turn, society's response to scientific and technological developments affects the direction of research and development.

Example Subobjectives		Example Activities	
4.41	Industry and government direct research and development according to perceptions of what society needs and wants.	4.411	Who should make the decisions about spending resources for disease control in the United States?
		4.412	Should federal regulation of research in genetic engineering be relaxed?
		4.413	What solutions could be proposed for the problems caused when third world countries continue to use DDT and other dangerous chemical insecticides?
		4.414	What mechanisms should exist to assure that decisions controlling new directions in research truly reflect the needs of society?
		4.415	Should the needs of society be the major factor determining the scientific research that should be done?
4.42	Developments in science and technology affect the quality of life.	4.421	Can the changes in life styles and standards of living brought by science and technology applications always be planned or anticipated?
		4.422	Were the spin-off benefits to society from the space program sufficient to warrant the costs?
		4.423	Can weapons research for our government be justified when the risk/benefits for society are considered?
		4.424	Should the quality of life be the only consideration in making technological applications?
		4.425	Is there danger to society in seeking knowledge just for the sake of knowledge?
4.43	The effort to meet the needs of society through research and development can have negative as well as positive results.	4.431	Should there be tighter controls on business and industry to prevent introduction of new products that may later be found to have negative effects on society?
		4.432	Can the needs of the present society be met while still protecting the interests of society in the future?
		4.433	Should there be concern that the time lags are constantly decreasing between discovering new knowledge and technological application, and between technological application and acceptance by society?
4.44	The demand of society for more and better products and services drives technological development.	4.441	Are there controls that can slow down the exponential rise of new technology? Should there be?
		4.442	Was the philosopher correct in stating that regardless of the consequences, when people have the possibility of doing something that has never been done before, it is not a matter of whether, but when?
		4.443	Why was there worldwide acceptance of the insecticide DDT followed by later rejection? Could this problem have been averted?

4.0 Science, Technology, and Society/Senior High School (continued)

4.5 Objective: Personal needs. The student shall understand that science and technology can affect individual lifestyles and that the individual, in turn, responds to affect science and technology.

Example Subobjectives	Example Activities
4.51 The context of a scientific/technological world determines to a large extent, the way an individual must live.	4.511 Is it really possible for a person (or a family) to live without being affected by science and technology?
	4.512 In what way does the computer impinge on the lives of individuals?
	4.513 What are the effects of the fact that it is possible to use a single change card anywhere in the country as well as in most parts of the world?
	4.514 What are the good and bad effects that come from satellite communication by telephone to any part of the world?
4.52 Any individual can exert pressure to bring support or control to bear on the progress of science and technology.	4.521 What are the alternatives available to the layperson who wants to affect the direction of research and development?
	4.522 Do all individuals have a responsibility to stay informed and to vote intelligently on matters involving science and technology?
	4.523 What are the advantages of scientific and technological literacy for the individual?
	4.524 Is the trained scientist or technologist more responsible for the events of a scientific/technological age than other citizens of the world?

Characteristics of Students and Science Program

Students

Students at the senior high school level are viewed as young adults in many ways, who often have adult responsibilities in terms of employment, social life, and career development. Yet some students have not developed adult reasoning abilities and may lack skills and experiences that are often expected of them. Therefore, evaluation procedures must account for variations, just as the instructional program must account for them. Although students at this level are characterized as formal thinkers, many have not yet acquired this ability or still use transitional or concrete thought patterns in unfamiliar contexts. Most senior high school students are highly sensitive and are striving for acceptance in the niche they have chosen for themselves.

Evaluation procedures must account for variations . . . .

Senior high school students often have ideas of future career plans; many may strive to specialize as much as possible. Some students are very competitive about grades and from previous courses have a definite expectation about the grades they should receive. Others will show little concern about their grades. Some will respond readily to the motivation of good grades; others will not.

Program

The senior high school science program gives primary emphasis to teaching science knowledge while maintaining the balance among the four science components. Traditionally required and elected courses make it nearly impossible to assure a complete science education for students beyond tenth grade. Yet, there is an overriding national concern for general scientific and technological literacy. To achieve this literacy, students need to demonstrate achievement of the specific objectives given in this guide, and have a positive attitude toward science and technology as demonstrated by personal actions. Concern should be given to considering the career options in science and technology, at least in terms of scientific knowledge and the skills related to these careers. While only a few students will seek careers in science or engineering, essentially all students will work in jobs increasingly influenced by technological advances. Science programs should serve all students by helping them achieve a literacy they can apply to all aspects of their lives.

The science program should be reviewed and carefully evaluated every five years . . . .

The science program should be reviewed and carefully evaluated every five years to ascertain that it is meeting the needs of students. Judgment of program adequacy prompts questions like the following.

Such questions provide information which can be used along with student achievement data to determine program adequacy.

- What is the proportion of students enrolled in science classes at each of the high school grade levels?
- What is the proportion of graduates who have completed chemistry, physics, and /or other advanced science courses?
- What is the level of success demonstrated by students who have graduated and subsequently enrolled in science and technology courses in colleges, universities, and technical schools?
- What is the extent to which courses incorporate current knowledge and use of contemporary technological apparatus?
- Is the recommended balance among the components of science education maintained?
- Does the program have built-in staff development procedures that are specific to the curriculum and aid in its revision?

Evaluation Tips

Evaluation at the senior high school level provides more than a set of scores designed to give students a letter grade for the course. Evaluation is a signal to students on what they are expected to learn; it reflects the program objectives. If evaluation is based only on recall, students will respond with memorized facts and other objectives will be ignored. It follows from the nature of the recommended objectives in this guide that complete evaluation requires a variety of evaluation techniques.

If evaluation is based only on recall, students will respond with memorized facts and other objectives will be ignored.

Problem Solving and Science Knowledge

Problem solving—a key component in all science courses—requires students to collect and analyze data and create appropriate displays and interpretations of these data. This requires not only mathematical competence in analysis, but also graphing techniques and extensive communication skills in describing investigations and their results. Evaluation of the students' competence in problem solving can be accomplished by observation in the laboratory, where each of the subobjectives of problem solving can be evaluated.

Paper-and-pencil tests can be used that ask students to analyze and interpret given data. This kind of testing can evaluate how well students analyze data, and, to some extent, explain objectives. Although grading essay questions is laborious, it is important that students' communication ability, especially technical communication, be developed and honestly evaluated. There is no simple technique that can replace the teacher's professional judgment of the adequacy and accuracy of written communication. The teacher should use great care in evaluating laboratory reports and essays. Evaluation of problem-solving abilities requires more than assessing the technical correctness of information; it involves a careful review of the logic employed in arriving at conclusions. The adequate evaluation of essays and laboratory reports involves assessing the

There is no simple technique that can replace the teacher's professional judgment . . . .

technical correctness of the scientific content, the correctness of the mathematical and analytic procedures employed, and the precision and quality of the language used in presenting the report.

The scientific knowledge taught in the various courses at the senior high school level should be evaluated applying all levels of cognitive development, including comprehension, analysis, and synthesis. High school students should display understanding of scientific knowledge using comparisons and contrasts, citing relevant examples from related experiments. For example, in evaluating understanding of the concept of limitation, the student might be expected to identify the factors that affect the carrying capacity of a particular region in terms of its ability to support one or more types of animal life. Students can be expected to deal with multifactor problems and display adequate understanding of the influence of simultaneous changes in one or more of the factors. In evaluating the other objectives within scientific knowledge, the student should not only demonstrate an understanding of the individual factors but also their interrelationship.

Courses should be evaluated applying all levels of cognitive development . . . .

Nature of Science and Science, Technology, and Society

The nature of science, which was treated in a much reduced fashion in the earlier grade levels, receives significant attention at the senior high level. Students need to understand the role of assumptions underlying various scientific principles and demonstrate that knowledge. A scientist's actions, which include precise recording and accurate analysis of data, need not only be practiced, but these ethics of the scientific enterprise should be expressed verbally and appropriately recognized in various test items. Students' understanding of the nature of the product of science—that is, the tentativeness of scientific knowledge and the ways in which knowledge changes—also should be evaluated.

A scientist's actions should be expressed verbally and appropriately recognized in various test items.

The science, technology, and society component is comprised of concerns which high school students should discuss in the science classroom and assimilate into actions in their personal lives. The impact of new technology on health, employment, and developments reported in the media warrant discussion within the class. Students need to demonstrate an awareness of current developments in science and their impacts (for example, genetic engineering and genetic counseling) beyond the classroom. Evaluating students' understanding and application of these issues sets a critical tone so the students understand this type of learning must continue throughout and beyond high school. Specific test items and essay tests should measure students' ability to recognize the political and economic implications of science and technology, the role of science as a power factor in the national and international economy, and the role of science and technology in providing satisfaction for societal and personal needs.

Students need to demonstrate an awareness of current developments in science and their impacts . . . .

Above all, an evaluation program needs to be developed that measures both student achievement and program adequacy in all four of the components of science education. A science curriculum can be well developed but still fail because the related evaluation strategy is not sufficient.